The Journal of

THE ROYAL AERONAUTICAL SOCIETY

JULY 1947 NO 439 · VOL. 51

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4 HAMILTON PLACE, PICCADILLY, LONDON, W.1

JULY NOTICES 1947

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

GARDEN PARTY AND GUILDHALL DINNER

The attention of Members is drawn to the application forms in this issue of the Journal and Monthly Notices for tickets for the Garden Party, to be held on 14th September and for the Dinner at Guildhall, to be held on 9th September.

CONTENTS OF THE JULY JOURNAL

Testing Civil Aircraft by P. A. Hufton, M.Sc.

The Prevention of Fire in Aircraft by W. G. Glendinning, B.A., and J. W. Drinkwater, D.Phil., B.Sc., Wh.Sc.

Cautionary Note Regarding Some Chemicals Used for Transition Indication by R. C. Pankhurst, Ph.D., A.F.R.Ae.S.

Correspondence and Reviews.

ANGLO-AMERICAN AERONAUTICAL CONFERENCE

The programme for the Anglo-American Conference is well under way and the following is a list of papers which the authors have agreed to read. More papers are being arranged and will be announced later.

American Lecturers

Theoretical Consideration of Stability and Control in High Speed Flight.	DR. THEODORE VON KARMAN Professor of Aeronautics and Director of the Guggenheim Aerodynamics Laboratory, California Institute of Technology.
Icing Problems.	ABE SILVERSTEIN Member of the N.A.C.A. Member of the Committee on Aerodynamics.
Column Theory.	FRANCIS R. SHANLEY Chief Structural Engineer, Lockheed Aircraft Corporation.
Helicopter Power Plants.	D. R. SHOULTZ
Light Aircraft Performance and Economy.	GROVER LOENING Chairman of the Helicopter Committee and Seaplane Committee N.A.C.A. Aeronautical Consultant for the National Advisory Committee for Aeronautics.

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Icing Problems.	Abe Silverstein Member of the N.A.C.A. Member of the Committee on Aerodynamics.
Column Theory.	Francis R. Shanley Chief Structural Engineer, Lockheed Aircraft Corporation.
Helicopter Power Plants.	D. R. Shoultz
Light Aircraft Performance and Economy.	Grover Loening Chairman of the Helicopter Committee and Seaplane Committee N.A.C.A. Aeronautical Consultant for the National Advisory Committee for Aeronautics.

The Future of the Reciprocating Engine.	RONALD M. HAZEN Chief Engineer of the Allison Division of General Motors. Chairman of the N.A.C.A. Committee on Power Plants for Aircraft.
Pilotless Aircraft.	R. R. GILRUTH Aeronautical Engineer N.A.C.A.
British Lecturers	
Performance in High Speed Flight.	W. G. A. PERRING Director of the Royal Aircraft Establishment and Director Designate of the National Aeronautical Establishment at Bedford.
Control in Low Speed Flight.	M. B. MORGAN Senior Principal Scientific Officer in the Aerodynamics Department (Flight Section) of the Royal Aircraft Establishment.
The Development of Thick Skin Construction.	D. WILLIAMS Senior Principal Scientific Officer in the Structural and Mechanical Engineering Department of the Royal Aircraft Establishment.
Structural Problems of Large Aircraft.	H. KNOWLER Director and Chief Designer of Saunders-Roe Ltd. of Cowes.
Helicopter Rotor Systems and Control Problems.	R. HAFNER Chief Designer of the Helicopter Department, Bristol Aeroplane Company Ltd.
Turbine Propeller Engines.	F. M. OWNER Chief Engineer of the Engine Division, Bristol Aeroplane Company Ltd.
Turbine Engine Icing Problems.	A. G. ELLIOTT Director and Chief Engineer Rolls-Royce Ltd.
Design Problems Arising from Sweep Back.	E. J. RICHARDS Chief Aerodynamicist at Vickers-Armstrongs Ltd., Weybridge Works.
Modern Operational Factors Affecting Airworthiness.	K. T. SPENCER Deputy Director on Airworthiness at Ministry of Supply, *and* P. A. HUFTON, Superintendent of Performance, Aircraft and Armament Experimental Establishment.

BIRTHDAY HONOURS

The following members have received awards in the Birthday Honours Lists:—

Knight Batchelor

Major H. R. Kilner, Companion.

C.B.E. (Military Division)

Group Captain F. A. Norton, M.Sc., M.I.Mech.E., M.Inst.T., Fellow.

O.B.E. (*Military Division*)
Wing Commander W. L. Houlbrook, A.M.Inst.C.E., Associate Fellow.
C.B.E. (*Civil*)
Mr. C. C. Walker, A.M.Inst.C.E., Fellow.
O.B.E.
Miss F. B. Bradfield, M.A., Fellow.
Mr. R. E. Hardingham, Associate Fellow.
A.F.C.
Wing Commander Elmer Coton, D.F.C., Associate.
Lt. Cmdr. (A) E. M. Brown, O.B.E., D.S.C., Associate.

HONOURS

Captain (E) M. Luby, R.N., Fellow of the Society, has been appointed by the President of the United States to the Legion of Merit, Degree of Officer, for services rendered to American Service personnel on matters connected with aero-engine development during the late war.

CLOSING OF THE LIBRARY FOR STOCKTAKING DURING AUGUST

The Library will be closed for stocktaking from 11th to 23rd August inclusive. Members are requested to return all books which they have on loan from the Library not later than Saturday, 9th August.

GLOUCESTER AND CHELTENHAM BRANCH

A visit has been arranged to the Bristol Aeroplane Co. Ltd. to inspect the Brabazon I on Saturday, 23rd August, at 2.30 p.m. The party is limited to 100. Applications should be made to the Hon. Secretary, J. F. Cuss, A.M.I.Mech.E., A.F.R.Ae.S., c/o Gloster Aircraft Co. Ltd., Witcombe, Glos., or to a Committee member.

GRADUATES' AND STUDENTS' SECTION

A visit has been arranged to the works of Miles Aircraft Ltd., Reading, on Saturday, 30th August, at 2.30 p.m. Applications to attend this visit should be sent to the Hon. Secretary, J. G. Roxburgh, 62 Fitzjohns Avenue, London, N.W.3.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received **before the 15th of the month** in order to be effective for the Journal for the following month.

ELECTION OF MEMBERS

The following members have been elected recently:—

Fellow

Joseph Robert Strandring (from Associate Fellow).

Associate Fellows

John Towers Ballett (from Graduate), Henry Edward Brown, Cecil William Browne, Leslie Bullock, Douglas Stuart Causer (from Graduate), George Cordrey (from Associate), Robert William Corkling (from Associate), Charles Beauvoir Dalison, Arthur Charles Freeth, Alfred Vivian Haile, Ernest John Hellier, Edward Henry Holman, Charles Ernest Jones, Lawrence Kelly, Ernest John Laker, James Lewis (from Associate), Robert Gavin McCoy (from Associate), Robert Gordon MacLeod (from Associate), William Charles Lewis Martin, Charles Trengove Nance (from Graduate), James Crockard Osborne, Edward Sainthill Pearse, Bryan Oliver Shepherd (from Graduate), Clifford Bevous Smith, Bernard Wild (from Graduate), Henry George Wright.

Associates

Sam Ashworth, Roland Halford Ayers, Walter Banas, Noel Rochfort Guyse Barker, Laurie James Gudgeon Bayliss, Arthur Collicott-Watts, Bernard Fitzgerald Collins, Edward William Cooper, Frederick Ernest Donovan, Terrence Urban Dunn, Mosze Etkes, Peter Goodwin Fielding, Benjamin Gordon Glass, John Swinford Harrison, Louis Thomas Hutchison Greig, Walter Edmund Hogsflesh (from Graduate), Cyril Francis Holloway (from Graduate), Roy Henry Laver, John William Lawrence, Kenneth Albert Major, William George Murray (from Student), John Augustus Nunn, Arthur Frederick William Ollett, Frank Cyril Petts, Wilfred John Tebby, William Edward Ronald Thain, John Geoffrey Toplis, Eugene Emile Vielle, Cyril George Weeks, Duncan Fairlie Wilson, Douglas Harold Yates-Smith.

Graduates

Kenneth Howard Dickenson (from Student), Joseph Brian Edwards, Bernard George Frampton, Leslie James Green (from Student), Peter Reginald James Harding (from Student), William Robert Hawks, Robert Guy Huggett (from Student), George Geoffrey Legg, Bernard David Longbottom, James Henry Sage, Thomas Leo Shelton (from Student), John Sutherland (from Student), Richard Ivor Beaumont Tavener (from Student), Norman Edward Percival Waldren, Robert George Ward.

Students

Robert Malcolm Allan, David Pitcairn Boulnois, Peter Ronald Cooke, Brian Eales, Kenneth Edgerton, D. J. Fermo, Kenneth Arthur Hammer, John Edgar Alfred Harrison, Archibald Geoffrey Henderson, Edward Vernon Hullah, Eric Jenner, Royle Bernard Dennis Jansen, Ronald John Jordan, Harindranath Vishwanath Khote, Ronald George Knight, Alan Rutherford McLean, Patrick Joseph McMahon, Douglas Moore, Richard Glyn Nicholas, Geoffrey Panter, Paul Leon Albert Raes, Peter Henry Sayer, Julius Sidon, Jasper William Morris Steer, Peter Francis Thompson, John Michael Thurston, Heinz Vogel, Brian Robert Vesey Walker, Alan Herbert Wickens.

Companions

Gordon Cowan Eddie (from Student), Norman Fox, Russell Hiram Pierce.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the following gifts: Copies of the official flying programmes at Hendon Aerodrome in 1913 and 1914 from A. R. Butler, Esq., Associate; album of photographs from F. F. Crocombe, Esq., Fellow, General Aircraft Ltd.; newspaper cuttings from C. V. Lane; and back numbers of the Journal from Captain C. W. E. Browse, Fellow, Air Commodore P. F. M. Fellowes, Associate, and Wing Commander A. K. Hunter, Associate Fellow.

Al

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N

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

BB.b.128.—Practical Aircraft Hydraulics. S. G. Bloxham. Pitmans 1947.

D.a.C.22.—Civil Aviation: Post-War Plans. Government of India. Directorate General of Civil Aviation.

D.b.268.—International Air Transport. Brig. Gen. Sir O. Mance. Oxford University Press. 1944.

D.c.115.—Airports: their location, administration and legal basis. Henry V. Hubbard, Miller McClintock and Frank B. Williams Harvard University Press. 1930.

EE.c.90.—Aircraft Engines. Volume II. (Second Edition, Revised.) A. W. Judge. Chapman & Hall. 1947.

EE.h.26.—Symposium on Materials for Gas Turbines. American Society for Testing Materials. 1946.

L.d.116.—*Notices to Airmen.* 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155.

M.c.75.—Civil Aviation Communications Handbook (formerly A.P.1692). Ministry of Civil Aviation. H.M.S.O. 1946.

N.d.3.—*Atom bomb and mass destruction. Raffaele Giacomelli. Editoriale Aeronautics, Rome.* 1947. (P.N.1a.)

S.d.95.—Air Power and War Rights. J. M. Spaight. Longmans. 1947.

S.d.96.—The Air Weapon 1914-1916. Volume II. J. R. Cuneo. Military Service Publishing Co., U.S.A. 1947.

N.A.C.A. Technical Notes

1190.—*Wake measurements behind a wing section of a fighter airplane in fast dives. De E. Beeler and George Gerard.*

1194.—*Effect of finite span on the airload distribution for oscillating wings. I.—Aerodynamic theory of oscillating wings of finite span. Eric Reissner.*

1231.—*The streamline pattern in the vicinity of an oblique aerofoil. Charles E. Watkins.*

1232.—*Effect of exhaust pressure on the performance of an 18-cylinder air-cooled radial engine with a valve overlap of 62 degrees. Leroy V. Humble, Tibor F. Nagey and D. S. Bosman.*

1237.—*Tank investigation of a powered dynamic model of a large long-range flying boat Langley tank model 180. J. B. Parkinson, R. E. Olsen and Marvin I. Haar.*

1238.—*The N.A.C.A. mixture analyser and its application to mixture-distribution measurement in flight. Harold C. Gerrish, J. L. Meem, Marvin D. Scadron and Anthony Colnar.*

1241.—*Experimental investigation of the stress distribution around reinforced circular cut-outs in skin-stringer panels under axial loads. Daniel Farb.*

1242.—*An analysis of the factors that affect the exhaust process of a four-stroke cycle reciprocating engine. J. D. Stanitz.*

1243.—*A spectrophotometric method for identification and estimation of alkylnapthalenic-type hydrocarbons in kerosene. A. P. Cleeves and Mildred S. Carver.*

1244.—*Effect of the tunnel wall boundary layer on test results of a wing protruding from a tunnel wall. R. A. Mendelsohn and Josephine F. Polhamus.*

1245.—*Summary of lateral-control research by Langley Research Dept., compiled by Thomas A. Toll.*

A.R.C. Reports and Memoranda

2083.—*The application of the calculus of variations to propeller design with particular reference to Spitfire VII with Merlin* 61 *engine. A. B. Haines and K. V. Diprose.*

2031.—*The compressible flow of fluids in ducts. R. R. Jamison and D. L. Mordell.*

2091.—*The method of characteristics in supersonic flow. G. Temple.*

2116.—*Note on the reduction of landing distance by the use of the tricycle undercarriage. J. R. Ewans.*

2105.—*Notes on the deflection of jets by insertion of curved surfaces, and on the design of bends in wind-tunnels. M. J. Lighthill.*

2070.—*An experimental investigation of the effect of airscrews on the longitudinal stability of a twin-engined monoplane. V. M. Falkner, H. L. Nixon and N. E. Sweeting.*

2087.—*Comparison of flight test determination of power absorption with airscrew strip theory. R. C. Pankhurst and E. M. Lowe.*

2108.—*The effect on drag of the ejection of air from backward-facing slots on a* 16.2 *per cent. Griffith aerofoil. J. H. Preston and C. R. Taylor.*

The following reports have also been received:—

National Research Council of Canada

Report No. 1. 1947.

Publications Scientifiques et Techniques du Ministère de l'Air

Reports No. 201, 202, 203, 204, and B.S.T. No. 108.

British Intelligence Objectives Sub-Committee

F.I.A.T. Final Reports Nos. 997, 992, 989, and 993.

Combined Intelligence Objectives Sub-Committee

C.I.O.S. Evaluation Report Nos. 215 and 110.

J. LAURENCE PRITCHARD,
Secretary.

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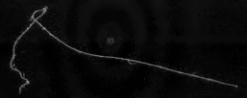

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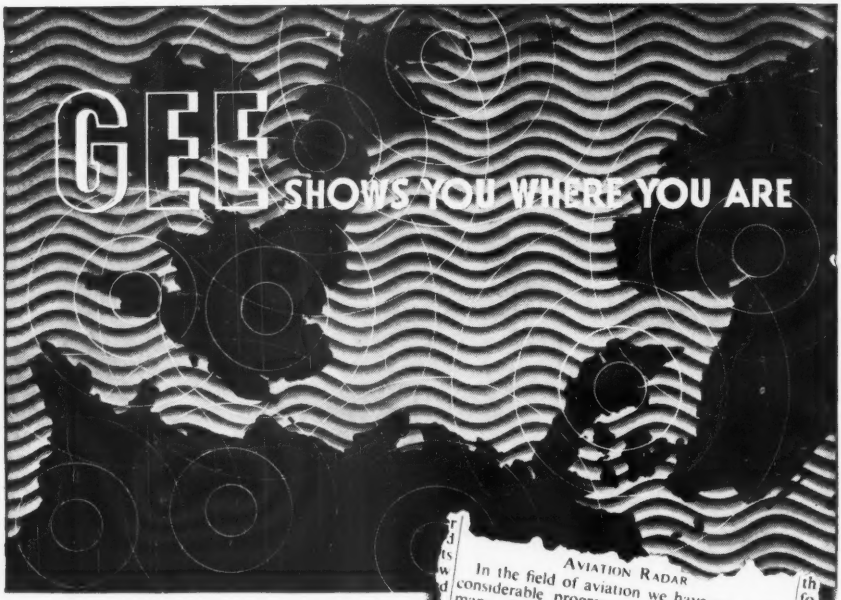

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Extract from an address made by Mr. T. A. Macauley, Chairman of A. C. Cossor Ltd., on 14th August, 1946, at the company's 8th General Meeting.

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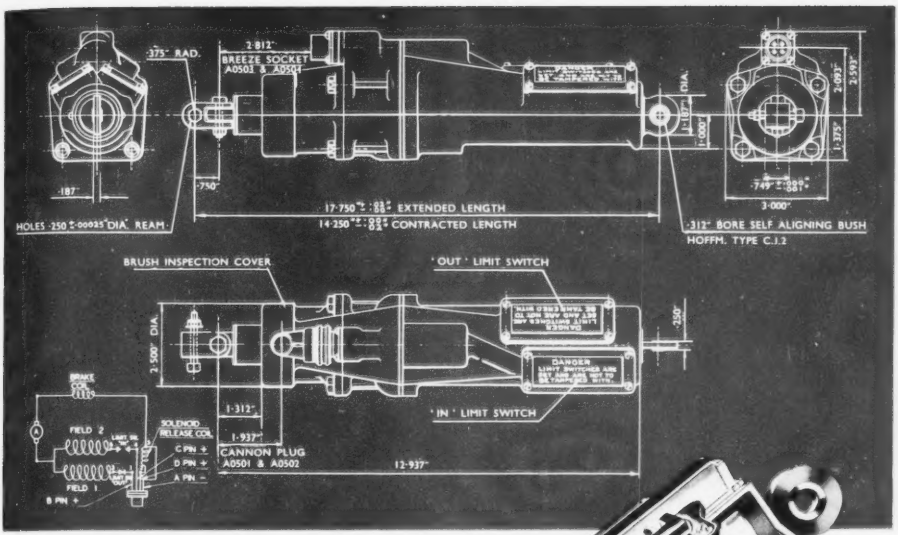

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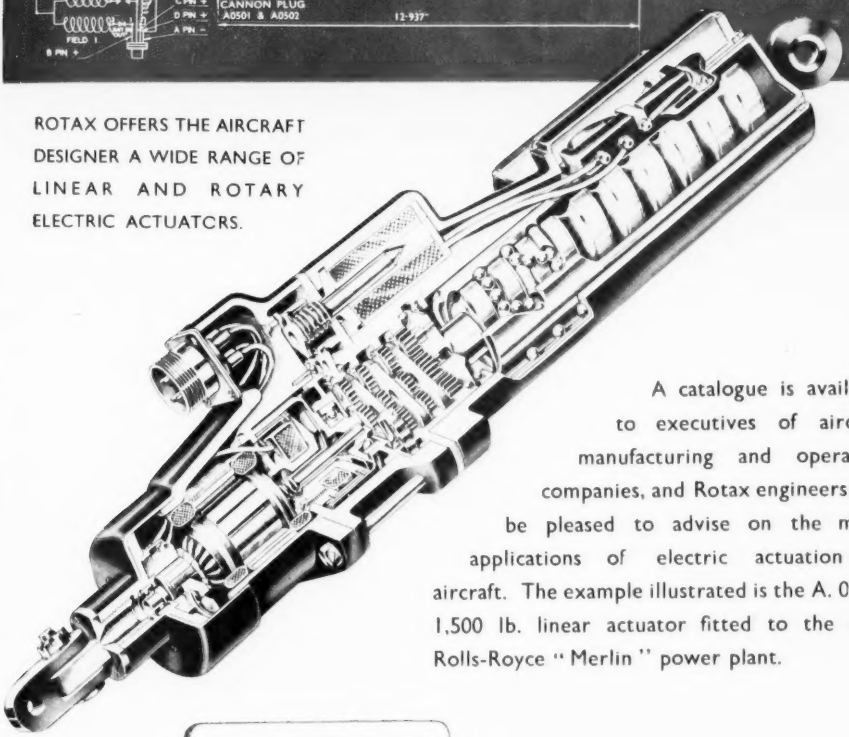

A catalogue is available to executives of aircraft manufacturing and operating companies, and Rotax engineers will be pleased to advise on the many applications of electric actuation in aircraft. The example illustrated is the A. 0501, 1,500 lb. linear actuator fitted to the civil Rolls-Royce "Merlin" power plant.

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MATERIALS AND METHODS, *March 1946*

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Published in conjunction with these journals, FLIGHT HANDBOOK (212 pages, 7s. 6d. net) is essentially a manual for the student, whilst GAS TURBINES AND JET PROPULSION (272 pages, 12s. 6d. net) by G. Geoffrey Smith, has been widely adopted as the standard text on the subject.

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FIRST Flying Doctor service established in Australia by Qantas at Cloncurry **1928**

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FIRST Four-engined Plane used in Australia . . . . . by Qantas on Brisbane-Singapore service (a DH86). **1935**

FIRST Through Flying Boat service to Singapore by Qantas, and — in association with Imperial Airways — to London . . **1938**

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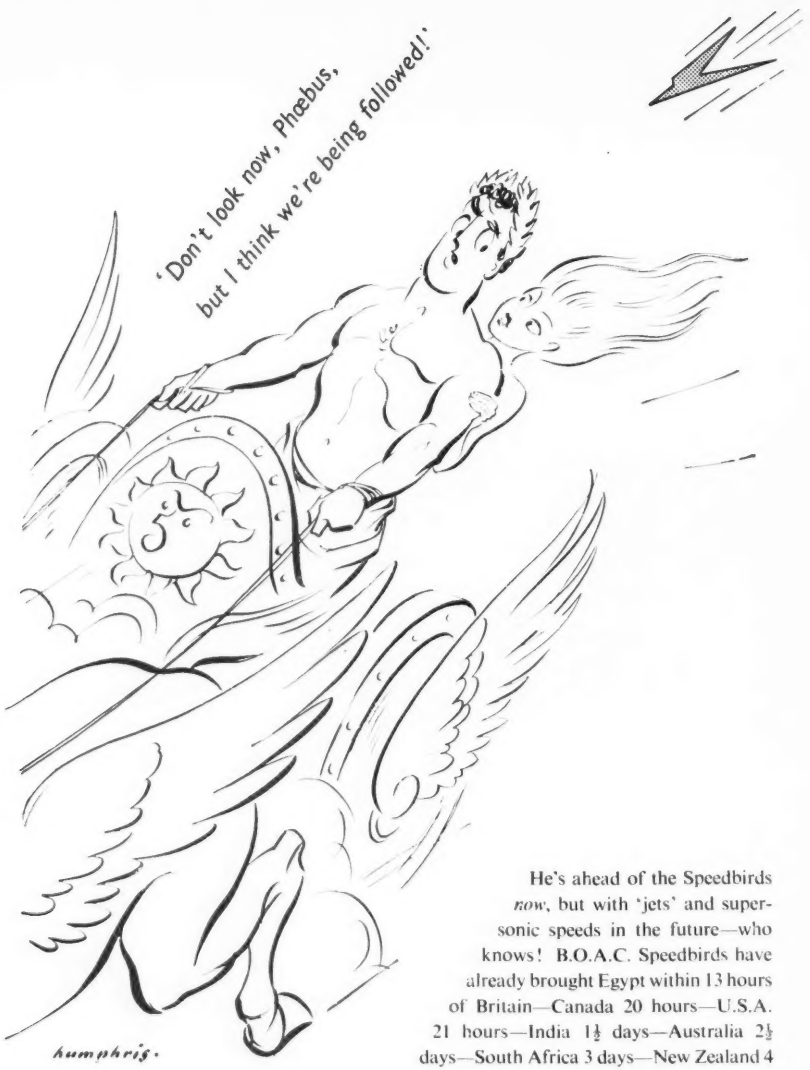

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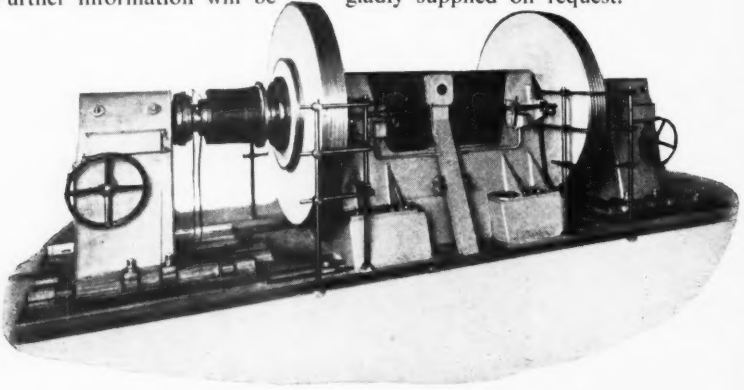

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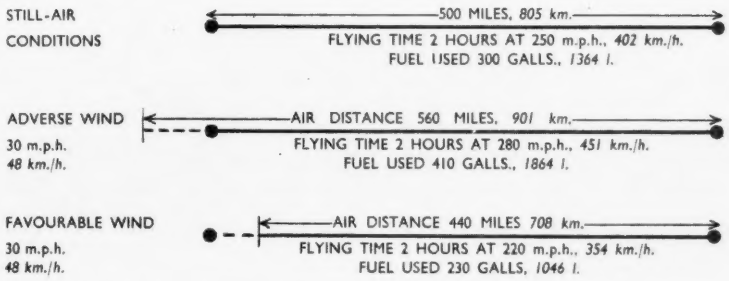
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With which is incorporated The Institution of Aeronautical Engineers

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The 711th Lecture read before the Society—on 17th April 1947 at the Institution of Civil Engineers, Great George Street, London, S.W.1. In the Chair, the President, Sir Frederick Handley Page, C.B.E., F.R.Ae.S.

TESTING CIVIL AIRCRAFT

by

P. A. HUFTON M.Sc.

Mr. Hufton took his degree in Mechanical Engineering at Manchester University in 1933. *The following year he joined the Royal Aircraft Establishment, working in the Flight Section of the Aerodynamics Division. In* 1946 *he was appointed Superintendent of Performance at the Aircraft and Armament Experimental Establishment, Boscombe Down.*

1. INTRODUCTION.

WHEN I was asked to give this lecture on Civil Flight Testing, I considered in what way any of my experience might be of general help to the Industry.

The tests which A. and A.E.E. make on civil aircraft are at the moment of three kinds:—

(a) Tests to prove compliance with Air Registration Board requirements for a Certificate of Airworthiness.

(b) Development tests for firms in order to suggest modifications to the aircraft occasioned by the results of tests made under (a).

(c) Tests made for the Ministry of Supply because some of the aircraft are for Ministry of Supply contracts.

The future organisation by which aircraft will be ordered for the operating companies is not known, so that it is impossible to say whether the tests of type (c) will continue to be made. These are not thought to be of much general interest and in any case, may well be covered by tests (a).

Tests of type (b) will be dealt with in general terms later. I can only say here that it is the profound hope of everyone connected with the prototype aircraft—not least the staff at A. and A.E.E.—that these tests will be unnecessary. It is not possible to forecast what detailed tests might be necessary on any aircraft so I will not discuss details of such tests.

The most important points of tests of type (a) will be dealt with in the second section of this lecture.

It is worth while considering here what body of regulations A. and A.E.E. work to in making their tests. Matters are, as everyone knows, in a state of considerable flux. There is an international set of requirements for airworthiness, given by P.I.C.A.O.[1] This becomes binding on production aircraft introduced into international transport service after 1951, and on all aircraft in such service after 1954. Unfortunately certain countries (we ourselves included) are still trying to have certain of the requirements altered, so that some of the value of this document as a text is destroyed. The importance of this document is large and at A. and A.E.E. we try to ensure that our test procedure will allow the aircraft to be measured against the P.I.C.A.O. requirements. We all accept that these are not mandatory, and will never be mandatory on certain of the aircraft types now being tested, but such comparisons should be of the utmost value to both the people carrying out the tests and to aircraft designers.

We also have A.R.B. regulations (British Civil Airworthiness Requirements).[2] Here again the requirements are being modified so that they will incorporate P.I.C.A.O. regula-

tions as far as we have agreed to do so, and a new set of documents superseding those given above are now being considered. The latter set of documents when agreed could be taken as the U.K. regulations equivalent to the P.I.C.A.O. regulations, and an aircraft meeting these domestic requirements can be assumed automatically to meet the P.I.C.A.O. requirements. In some respects our domestic requirements are more severe than the P.I.C.A.O. regulations, and in other cases, alternative interpretations of the P.I.C.A.O. regulations (permitted by P.I.C.A.O.) have been adopted.

One notable example of this will be found in our domestic regulations for longitudinal stability, dealt with at more length later. Here an alternative interpretation has been used, which is in practice stiffer than the P.I.C.A.O. regulation, because the P.I.C.A.O. regulation did not seem to meet possible contingencies.

Bearing these different documents in mind, it is proposed in this lecture to refer mainly to the P.I.C.A.O. requirements as a working text, with suitable amendments as proposed in the most recent A.R.B. documents.

2. SOME OF THE MORE INTERESTING AND IMPORTANT TESTS.

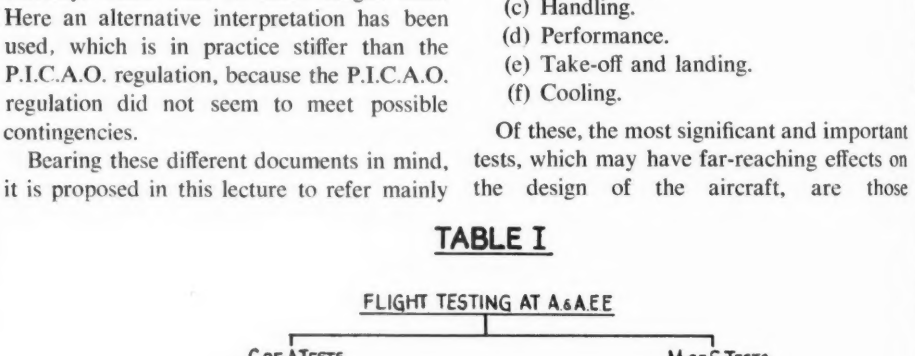
The various flight tests of civil aircraft can be divided and subdivided as shown in Table I.

Leaving out the tests listed for the Ministry of Supply, for the reasons indicated above, it will be seen that the tests are generally split under six headings for convenience in testing.

(a) Preparatory and General.
(b) Functioning.
(c) Handling.
(d) Performance.
(e) Take-off and landing.
(f) Cooling.

Of these, the most significant and important tests, which may have far-reaching effects on the design of the aircraft, are those

TABLE I


FLIGHT TESTING AT A&AEE
C OF A TESTS
M OF S TESTS
RESEARCH
MOSTLY COLLECTION OF DATA
DEVELOPMENT
CLEARING UP SNAGS ETC.
INFORMATION
SPECIFIC AIR RANGES, CABIN HEATING ETC
MISC
NOISE RADIO VIBRATION ETC
PREPARATORY & GENERAL
PEC CO CONTAMINATION COCKPIT ASSESSMENT BEST FLAP ANGLES. BEST CLIMBING SPEEDS DETERMINATION OF CRITICAL ENGINE ETC
FUNCTIONING
FUEL SYSTEM DE-ICING FEATHERING CONTROL FRICTION RATE OF U/C & FLAP OPERATION ETC.
HANDLING
CONTROLLABILITY-ON SYMMETRIC POWER-ON ASYMMETRIC POWER STABILITY - LONGL - LATERAL AND DIRECTIONAL BEHAVIOUR AT LOW SPEEDS & AT STALL ETC.
PERFORMANCE
MEASUREMENT OF STALLING SPEEDS RATES OF CLIMB WITH ONE ENGINE FAILED ETC.
TAKE-OFF & LANDING
DISTANCE TO TAKE-OFF AFTER ENGINE FAILURE. DISTANCE TO LAND AFTER ENGINE FAILURE
COOLING
COOLING ON TAKE-OFF COOLING ON CLIMBS & LEVELS WITH ONE ENGINE FAILED

concerned with take-off, performance and handling with one engine failed, the stability tests, the stalling tests, and certain of the functioning tests.

It is convenient to deal with the performance and handling trials with one engine dead together with the take-off tests, as certain of the former tests are bound up with the new take-off tests and form a unified whole. The next four subsections will deal with the take-off tests, the stability tests, the handling tests, and the functioning tests.

2.1. Take-off tests.

The fundamental ideas about take-off with one engine dead date back longer than most people realise. Von Baumhauer of the Netherlands[3] wrote a paper on the subject before the war, and the Douglas Company did tests on an early DC-2 before 1935.[4]

Why are we putting in tests which cater for the chance of engine failure during take-off? An American figure gives 3,000 hours to 9,000 hours between "severe" failures of an engine; another figure gives one engine failure per year per aeroplane. Again, American sources suggest that half the engine failures occur during take-off. These figures are in general agreement with our own military experience.

Roughly, this means that we can expect an engine failure in flight every 2,000 flights, and of these failures one will happen during take-off once every 4,000 take-offs. Some American airports are even now scheduling 200 take-offs per day; and this kind of figure is one which we may well see if transport aviation becomes as cheap and as safe as we all wish it to be. Thus on such an airport we can expect to see an engine failure during take-off every 20 days.

We must ensure as far as possible that engine failure will not result in an accident: we are not suggesting that we can make the accident rate zero, but we should try to get it as low as possible. Our aim should be, if I may suggest a figure, to obtain immediately a figure of one accident say, every 10 years at any one airport—a figure which would mean that we should try to make the aircraft such that the pilot has at least 199 chances of getting away with it out of 200. There is another point of view, too—if the pilot is given a drill to carry out, he expects that it means that if he does what he is told, he ought to have a good chance of recovering. The figure quoted above might not look very bright to the pilot—and is certainly not put forward as our ultimate goal.

We cannot guarantee that the take-off drill is safe unless we are assured of three things.

(i) The pilot is given figures for climbing speeds and so on at which he can retain control if an engine fails.

(ii) The despatcher, operator, or pilot is given figures for all-up weight of the aircraft for which it "fits" with one engine failed, the airport dimensions and its surrounding country.

(iii) The general performance of the aircraft with one engine failed is so high that the take-off performance is not "critical" to small changes and errors in atmospheric conditions, weight, pilotage, and so on.

These three points will be discussed further in the next few sections.

Take-off Drill.

An idea of this drill is shown in Fig. 1. We start our take-off on all engines. If an engine fails fairly early we probably have not got sufficient directional control to keep the aeroplane straight (unless we have a very good steerable tricycle), so we stop. Even if we had good control, there would probably not be much point in carrying on with one engine cut.

If we have a tailwheel undercarriage, we probably unstick at some point where we can do it comfortably but we don't retract the undercarriage until we are quite sure we won't sink back if an engine stops. Even

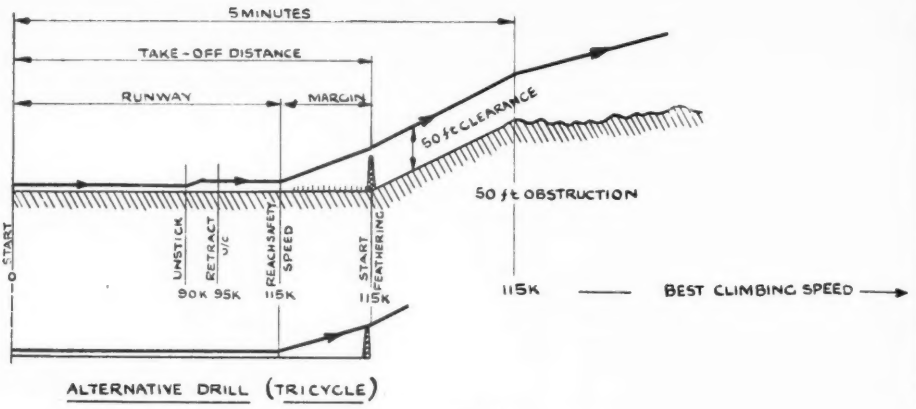


Fig. 1.
Take-off drill.

after we've unstuck we keep close down to the ground till we reach our safety speed. With a tricycle we may stay on the ground all the way till we reach our safety speed.

During this stage, if an engine cuts before we have enough control, we have no alternative but to stop. If it cuts after we have enough control, we have to decide whether it pays to carry on with our take-off, or come to a halt.

When we reach safety speed, and not till then, we start to climb away, provided that we are able to climb away with sufficient margin to clear all the surrounding obstacles. In some cases it will still pay us to reland and stop if an engine cuts on the climb away.

Thus, what we have to think about is, briefly:—

(a) The speed at which we have enough control to keep straight after an engine cut.

(b) The speed at which we can safely retract the undercarriage.

(c) What is our safety speed?

(d) At what speed, if an engine cuts, we decide to carry on instead of stopping.

(e) Whether on a particular airfield we *can* safely carry on or stop after engine failure at any point.

Example: Still looking at Fig. 1, let us take an example.

Let us suppose for the moment we have an aeroplane that climbs comfortably when one engine is not working. It is easier to talk about definite figures, so we will take an imaginary four-engined aeroplane with a weight of 60,000 lb., with an engine-off stalling speed of 95 knots with 15° of flap, and with a tail-wheel undercarriage. We are going to consider the best take-off that can be made with safety in the event of an engine cut.

The operating manual will tell the pilot to hold the aeroplane close to the runway till he reaches 115 knots. He is then to climb away at a steady 115 knots till he is clear of all surrounding obstructions. He is to retract his undercarriage at 95 knots.

If an engine failure is indicated before the aircraft reaches 90 knots, he is to throttle back his engine and come to a stop.

If an engine fails at a higher speed, he is to continue to accelerate to 115 knots, or to remain at 115 knots, as the case may be and complete his take-off, climbing away at 115 knots. He will, as before, retract his undercarriage at 95 knots and he will continue his climb at the same speed until he has been going for 5 minutes, at take-off power, when he will settle to climbing conditions. He will

feather the propeller as soon as he is certain the engine has lost all power permanently: but for the sake of making tests, we assume that the propeller is feathered at 50 ft. This is shown diagrammatically on Fig. 1.

That is his drill. Now let us look at the reasons for it.

Some definitions.

We have already stated the points about which we have to think. Now we will put them down in a more technical form, and also in a different order.

First: The minimum control speed on or near the ground (sometimes called V_{mcg}). This is the minimum speed, during the take-off acceleration period, at which if the engine fails the pilot can retain control to be able to continue accelerating safely.

Second: The take-off safety speed. This is the speed at which it is safe, from both handling and performance aspects, to climb away. Before we can define it we also want the next three.

Third: The stalling speed in the take-off condition (called V_{s1}).

Fourth (*a*): The minimum control speed on the climb (sometimes called V_{mc}). This is the minimum climbing speed at which, if an engine fails suddenly during the steady climb at take-off power, you can still maintain control of the aircraft.

Fourth (*b*): The minimum speed at which the aeroplane can be held comfortably with one engine stopped.

Fifth: The critical point, which as far as the pilot is concerned, is the point at which the aeroplane reaches the critical speed. If an engine fails before this speed is reached, the pilot should stop his take-off. If after this speed, he should carry on.

Sixth: The point of undercarriage retraction.

These definitions are still a bit vague, so now we will look into them in detail, and consider what flying tests they will involve.

Minimum control speed on or near ground.

The take-off drill said that "if an engine fails at a higher speed than 90 knots, the pilot is to continue his take-off." What are the reasons behind this statement? At the moment, let us consider only controllability.

Let us suppose that tests on this aircraft have shown that with any cross-wind up to 8 knots component, even if an engine cuts at as low a speed as 75 knots, there is enough directional control and enough acceleration for the take-off to be continued. To take a speed of 75 knots would, however, leave little margin, so we will tell the operating pilot that it is safe, as far as controllability goes, to continue his take-off after an engine failure at, say, 85 knots. This margin takes care of variations between aeroplanes of the same type and small errors in A.S.I. readings. It does not take care of the large cross-winds, but as we have to take *some* risk, we may decide that the probability of having a cross-wind component higher than 8 knots at the same time as an engine failure in the early stages of take-off is fairly remote.

The aeroplane may have been controllable because it had so much rudder power. But suppose it had had a fairly large fin and a not very effective rudder and also reasonably good ailerons. We might have found that we could not keep it straight on rudder alone, with the wings level, but by banking the dead engine up, and using only 2° to 3° of bank it was quite possible to keep straight. (The bank introduces sideslip, and the sideslip acts on the fin to hold the aeroplane straight.) In that case we could not have kept the aircraft straight while it was on the ground, but could have done it once it was airborne. Say the aeroplane would unstick easily at 80 knots, and could then be held straight and airborne with an engine cut, we would call the minimum control speed perhaps 85 knots, to give us a margin. This minimum control speed would be independent of cross-winds, apart from the question of possible dangerous drift.

Or, going to the other extreme, take an aircraft that had rather poor aerodynamic directional characteristics, but a good steerable tricycle undercarriage. We might find that we could control after an engine cut at a low speed, so long as we stayed firmly on the ground, and we would have to remain firmly on the ground until we had reached an airspeed at which the rudder could safely take over for steering.

With all this, we have not arrived at our figure of 90 knots. That we will have to arrive at later.

What then should be the test conditions under which we must find this minimum control speed?

(a) Take-off weight and most adverse C.G. position.

(b) Take-off flaps.

(c) Undercarriage down (in some individual cases, our common sense will show that we should also try it undercarriage up).

(d) All engines operating at maximum take-off conditions. The one engine cut at various speeds. The only practical way of doing this is to throttle back suddenly, without, as far as possible, the pilot knowing. The engine to be cut must be the one giving the worst effect.

(e) As the pilot is going to be caught rather suddenly, we don't allow him to reduce the drag of the windmilling airscrew by pulling back the r.p.m. control or feathering. He should not do this in practice, anyway, as the engine might pick up again.

(f) No differential braking to help keep the aircraft straight, as any braking will reduce the take-off performance.

(g) Control loads and movements must not exceed those which can be put on quickly and comfortably. For example, you cannot expect the pilot to put on more than about 90° control wheel movement even if aileron loads are fairly light.

(h) The aircraft accelerating along a horizontal path, and subject to any ground effects.*

(i) The aircraft running along the ground, or flying just off the ground, according to individual aircraft and the stage of the take-off at which the cut is made.

(j) If bank is used it should not be a perceptible amount, as a pilot taking off at night or in bad visibility will not care to put on much bank close to the ground.

(k) If we allow any yaw to develop this must be controllable to the extent that not only can the yaw be stopped, but also the aircraft can be brought back to its original heading without going over or too near the edge of the runway.

(l) For obvious reasons, the trimmers must not be touched.

Take-off safety speed.

Why, now, did the drill say that the pilot must hold the aircraft down to 115 knots, and then climb away at that speed? Well, the speed at which he climbs away must obviously be the lowest possible consistent with fulfilling the following conditions:—

(a) There must be a margin above the stalling speed.

(b) There must be adequate control should an engine cut during the climb away.

(c) There must be adequate control should an engine have already cut before climbing away.

(d) There must be sufficient rate of climb and gradient of climb on all engines,

*Because of the last requirement A. and A.E.E. do their tests on actual take-offs, by cutting an engine at gradually reducing speeds, until they get so low a speed that control becomes inadequate. The Americans prefer to do their tests in the air, accelerating in level flight from a speed just above the stalling speed with all engines at take-off power and making no allowance for ground effects.

or with one engine windmilling, to enable the aircraft to get safely away.

With these conditions we can start defining our safety speed. First, what is the state of the aircraft as it climbs away?

Weight, c.g. and flaps as before.

Engines operating at maximum take-off power. One engine possibly windmilling with the r.p.m. control in the take-off position (the pilot is still hoping the engine will pick up).

Undercarriage up, or coming up. One might say the undercarriage was anywhere between down and up.

The aircraft climbing at a steady speed.

Any ground effect tapering off.

With these things in mind we can discuss the detailed conditions (a) to (d) above.

Stalling speed.

The stalling speed we should consider is the stalling speed of the aeroplane with take-off flap, undercarriage down or up (whichever gives the higher stalling speed), with one engine (the one giving the highest stalling speed) windmilling in fine and the others at take-off power. This is not always easy to measure so we may have to think in terms of engine-off stalling speed. For a twin-engined aeroplane, if an engine is cut one wing will be in a practically engine-off state. We take all the usual precautions to obtain an accurate stalling speed and particularly, if we do the test with asymmetric power, we try to circumvent errors due to an unknown position error because of sideslip.

The margin above the stalling speed we like to have is 15 to 20 per cent., to allow for differences between individual aeroplanes and errors in A.S.I. systems.

Minimum control speed on the climb.

This is the lowest speed at which, while climbing steadily with TO power on all engines, the aeroplane can be kept under control if an engine suddenly fails. As before, we simulate engine failure by sudden throttling back, without touching the r.p.m. control. The undercarriage should be up or down, whichever gives the worse condition. Control loads and movements must be reasonable. Ground effect should be neglected. A bit of yaw and a fair amount of bank, say 5°, should be allowed, as the aircraft is climbing away from the ground.

When we have found this minimum control speed, we can expect that, as at this speed we can cope with a sudden engine cut, we can also be quite happy if an engine has already cut at an earlier stage.

It is convenient, when testing, to have the worst engine windmilling and to find first, by gradually reducing speed, what is the lowest speed at which the aircraft can comfortably be held straight. Then we fly at that lowest speed on all engines and suddenly cut the worst engine and see if we can hold the aircraft straight. Usually we can.

Getting back now to our safety speed. We can now cover both (b) and (c) of the above conditions by putting, say, a 10 per cent. margin on the minimum control speed on the climb.

Suppose our engine-off stalling speed was 95 knots and we base our requirements on the engine-off stall. Fifteen per cent. margin on that gives 110 knots. Our take-off safety speed must not be less than 110 knots.

Suppose our minimum control speed on the climb was 96 knots (determined, say, by pre-stall buffet or perhaps by rudder load). Ten per cent. margin on that gives 105 knots. Well, we still have 110 knots for the safety speed.

But does climbing at 110 knots give a sufficient rate and gradient of climb to meet our operational requirements, with a margin for various factors such as temperature effects? We say that we are considering the climb at a point where the undercarriage is up but the airscrew still windmilling (although there are arguments that we should think about the climb while the undercarriage is still down, and others that we should be in

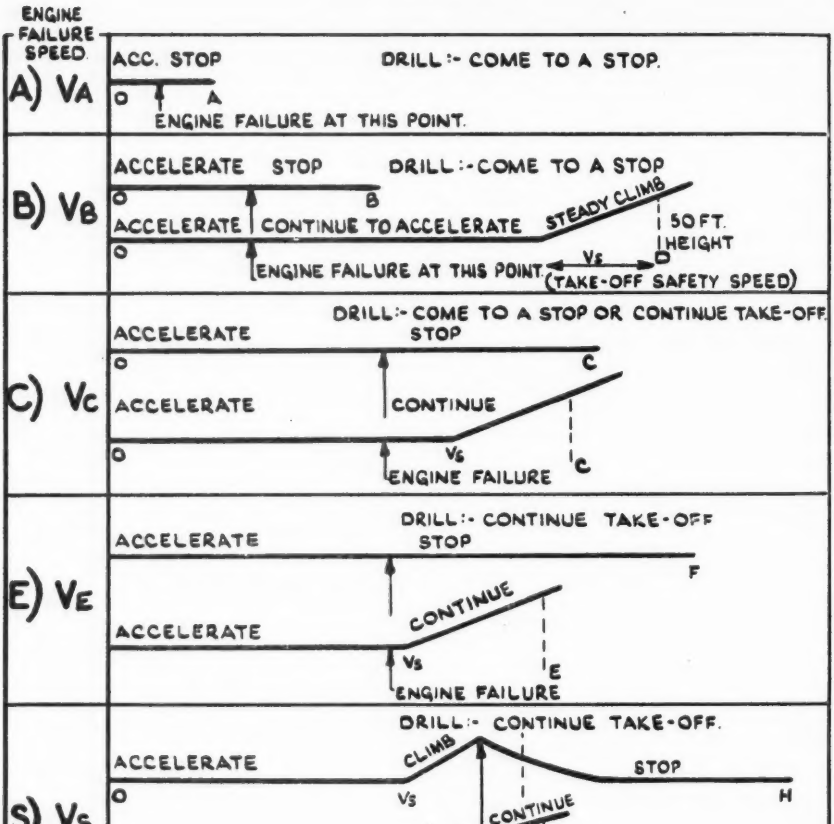


Fig. 2.
Take-off critical point.

the undercarriage up and airscrew feathered state) and accordingly do a climb in that condition at take-off power, to find, say, our rate of climb just too low. So then we do some partial climbs, and eventually find we meet the rate-of-climb conditions at between 115 and 130 knots. We shall return later to these climb requirements.

Any speed between 115 and 130 knots will then meet all the conditions for take-off safety speed. To get the least take-off distance, we take 115 knots.

Critical speed and take-off distance.

This is the least well understood of the lot. We told the pilot it was *safe* to continue his take-off if an engine failed at 85 knots. It was, from the handling point of view. But if he had continued his take-off, he would have used more aerodrome than if he had come to a stop (see (B) of Fig. 2). So we tell him to come to a stop.

If the engine had cut at 110 knots, or, say, had cut at 115 knots when he was half-way up on his climb-away to the 50 ft. screen, he

would have used more aerodrome by re-landing than by completing his take-off (see (E) and (S) of Fig. 2).

But with an engine-cut at 90 knots, he would have used an equal amount of aerodrome whether he had gone on or come to a stop (see (C) of Fig. 2). And this distance OC on the figure is the maximum length of aerodrome he is likely to want should an engine cut on take-off at any stage Provided, of course, that he always comes to a stop if the engine cuts at less than 90 knots, and continues his take-off if the engine cuts at a higher speed.

This is the critical speed, and the point at which the aircraft reaches this speed is the critical point.

If the aircraft had no acceleration and no rate of climb after an engine cut, then even if the engine cut had occurred when the aircraft was at 49 ft., the aircraft would never get to 50 ft., and the pilot would always have to reland and come to a stop. At the other extreme, if we had a tricycle aeroplane with poor brakes but with a good acceleration and rate of climb with one engine out, it would pay the pilot to complete his take-off even if an engine cut at a very early stage *provided* that he had enough control.

To find this critical speed, we measure first a number of accelerate-and-stop distances, cutting an engine at various speeds during take-off. After the engine cut the pilot takes corrective action with differential throttle, differential brakes if the aircraft is still on the ground, rudder, ailerons, steerable nose-wheel if he has one, then as soon as everything is under control, and he has re-landed if he is already airborne, he jams on the brakes and comes to a halt. The measured distances are corrected to zero wind, standard atmosphere, standard friction coefficient and so on, and plotted against the speed at which the engine was cut, giving us a curve something like OABCFH in Fig. 3.

In the same way, we measure the distances to take-off over a 50 ft. screen after engine cuts at various speeds *above* (obviously) the minimum control speed on the ground, and get the curve DCEG. If the two curves intersect, the point of intersection gives us the speed at which distances to complete take-off or to stop are equal, and this is our critical speed.

If they don't intersect, that means the distance to complete the take-off is always greater than that to come to a stop, and so the aircraft should always come to a stop after an engine cut.

Point of undercarriage retraction.

When should the undercarriage retraction be started? If you are comfortably airborne, with no likelihood of sinking back after an engine cut, when you reach the critical speed, you do not want to use your undercarriage again, so why not dispense with its drag when you reach the critical speed? That is why our take-off drill has told the pilot to retract at 95 knots.

However, the critical speed may be lower than the engine-cut unstick speed, and you will have to wait until you are comfortably past the latter before you retract. Again, you may be depending on a tricycle undercarriage to give you directional control, in which case you may not want to unstick until you get to the safety speed. Emphatically, you must not retract your undercarriage until you have reached a speed high enough to be quite certain you will not sink back if an engine cuts.

P.I.C.A.O. regulations are that the undercarriage is left down until the safety speed is reached. This avoids a lot of argument.

Performance of the aircraft.

Rate and gradient of climb.

We measured our climb with the undercarriage up but the airscrew windmilling. Unless the aircraft is designed so that failure of one engine makes undercarriage retraction impracticable, there are long odds against engine failure and hydraulic failure occurring

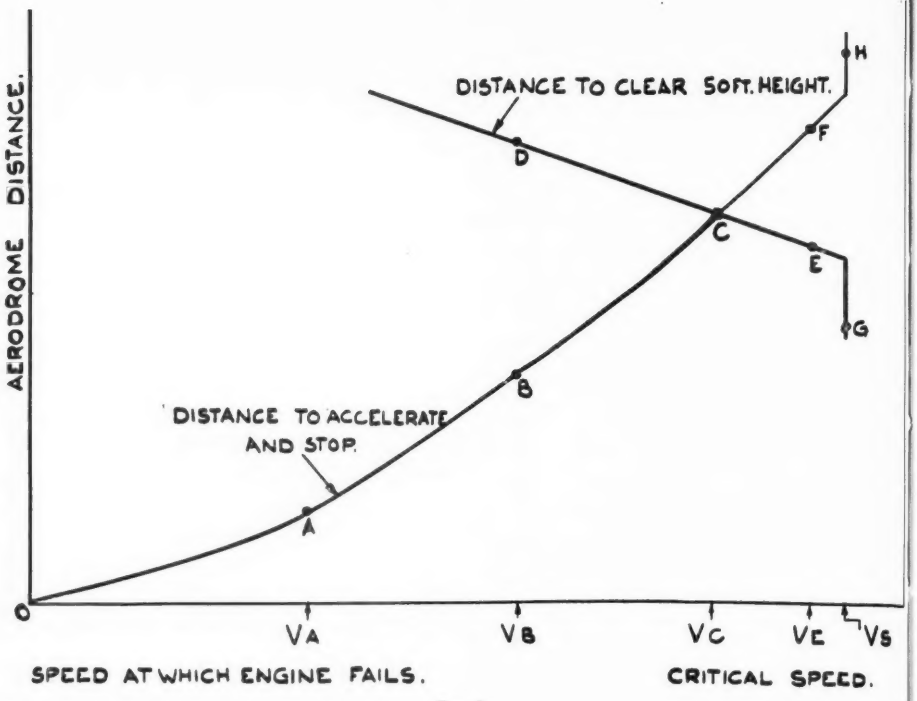


Fig. 3.
Take-off critical point.

simultaneously, so we forget that. Airscrew feathering is not so certain. So if we are thinking of the rate and gradient of climb after we have got over the 50 ft. screen we are being rather, but not unduly, pessimistic. If we are thinking of them before the 50 ft. screen, we are supposing the undercarriage drag to disappear fairly smartly, which is reasonable. We can say that while the undercarriage is still out we have some ground effect to help us, and by the time the ground effect has disappeared so has the undercarriage.

Acceleration during ground run.

We have another untidy loose end to clear up. We established a minimum control speed near the ground as 85 knots and the critical speed as 90 knots, and we told the pilot that if an engine failed at 90 knots he was to continue to accelerate to 115 knots.

It would, however, make the pilot feel a little foolish if he found that when he was trying to continue his take-off with one engine out he had zero or even a negative acceleration. This might happen in spite of our tests having been made successfully, if the operating aeroplane was a bit down on power, or if the day was very hot, or the aerodrome at a high altitude, or through a combination of all these things.

So, on our tests we should make sure that there is enough reserve power to give some minimum standard of acceleration. We could do this in one or two ways:—

(a) If we had the instruments for the purpose, we could measure the actual acceleration during take-off after an engine had been throttled back. For this we would need a sensitive and accurate accelerometer, or some

accurate method of obtaining displacement against time. (The snag about the latter method is that if you get a curve of displacement against time you have to differentiate it twice to get acceleration. Each time you differentiate you introduce a nice error.)

(b) We can obtain a relation between rate of climb and acceleration, if we say the drag of the aircraft and the efficiency of the propeller during the climb (at a particular speed) is the same as during take-off at that speed. The relation is

$$\alpha = \frac{Rg}{60V}$$

where

$g = 32.2$ ft./sec.^{2}
α = acceleration in ft./sec.^{2}
R = rate of climb in ft./min.
V = true speed in ft./sec.

(*e.g.* 360 ft./min. at 115 knots equals 1 ft./sec.^{2} or roughly 0.7 m.p.h./sec.)

Therefore we could measure the rate of climb at take-off power, with one engine windmilling, and the aircraft in the take-off configuration and say that was equivalent to a certain acceleration on take-off plus any bonus we get from ground effect.

One of the modifications proposed at the most recent P.I.C.A.O. Airworthiness Meeting was to introduce a requirement for the rate of climb in this configuration.

Zooming.

If the pilot does not fly at a steady speed during the climb away, he can gain some height by zooming. Under some circumstances it may conceivably pay to gain some immediate height by losing speed.

The gain in height is

$$h = V.\Delta V/g$$

where

h = height gained in ft.
V = original speed, ft../sec.
ΔV = loss of speed, ft./sec.

Thus, suppose we pull the nose up so that speed drops from 115 knots to 110 knots in, say, 10 seconds. We then gain 50 ft. in 10 seconds, which artificially increases our rate of climb by 300 ft./min. It is obvious what difficulties this can introduce in doing test take-offs. Wind gradients near the ground, or gusts, will have a similar effect.

Methods of elements.

While in this country we prefer to measure our distances by doing actual engine-cut take-offs, the Americans prefer what they call the

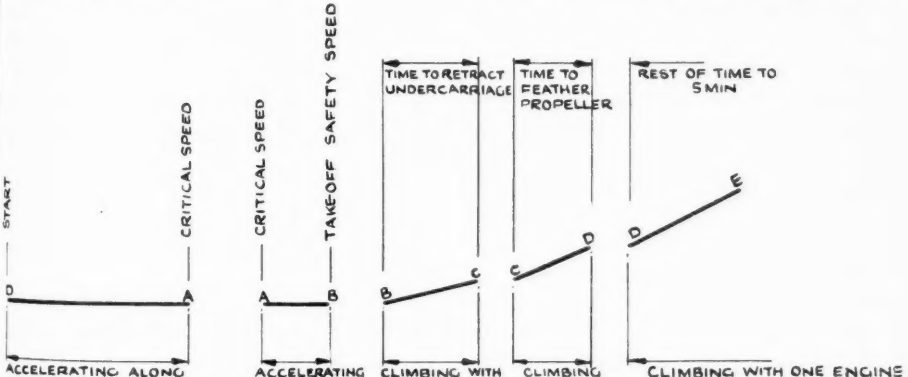


Fig. 4.
Method of elements.

"Method of Elements" (see Fig. 4). This involves making the following tests:—

(a) Determining take-off safety speed.

(b) Measuring the distances to accelerate from start to various speeds on the ground on all engines.

(c) Measuring the distances to accelerate from various speeds to the take-off safety speed, with one engine out.

(d) Finding the time taken to retract the undercarriage and to feather an airscrew, at take-off conditions.

(e) Finding the rate of climb at take-off safety speed at take-off power with one propeller windmilling and the undercarriage down.

(f) Same again but with undercarriage up.

(g) Same again but with undercarriage up and propeller feathered.

(h) Measuring the accelerate-stop distances after engine cuts at various speeds.

Having got all these, assume a critical speed, then draw

OA—the distance taken when accelerating along the ground from start to critical speed, on all engines.

AB—the distance taken when accelerating along the ground from critical speed to take-off safety speed.

BC—the path of the aeroplane when climbing with one propeller windmilling, undercarriage down, for the length of time taken to retract the undercarriage. Ground effect is neglected.

CD—the path of the aeroplane when climbing with one propeller windmilling, undercarriage up, for the length of time taken to feather the propeller.

DE—the path of the aeroplane when climbing with one propeller feathered, undercarriage up, for the remaining time up to 5 minutes after start of take-off.

Join the lot together and you have a synthetic take-off. Do this for a number of assumed critical speeds, until you can draw the same picture as we had in Fig. 3, and so find your actual (synthetic) critical speed.

This method is said to give a rather pessimistic take-off distance. It has one great advantage—that of being easy to correct to various standard conditions.

General comments on take-off.

You can now see how these various requirements of the A.R.B. regulations fit into the general scheme of supplying information on the take-off which will allow operators and pilots to attain a reasonable level of safety, and how we interpret some of the more "unintelligible" of the P.I.C.A.O. requirements.

You will have taken note that the "minimum control speed" of P.I.C.A.O. has become three minimum control speeds—but we may well lose one of these as we get more experience.

You will have seen that we wanted some form of climb requirement (and/or acceleration requirement) in order to guarantee that the take-off can continue to be made in a few of the adverse circumstances. This is usually obtained by limiting the all-up weight of the aircraft—usually in terms of the aerodrome altitude. One point that has turned up that has considerable importance in the flight testing of civil aircraft is the way in which the all-up weight affects the rate of climb. Obviously if an aircraft is slightly down in rate of climb—say 50 ft./min. one way to improve matters is to reduce the all-up weight.

It is not, of course, possible to give a universal figure for the percentage change in all-up weight required to gain this rate of climb, but a figure of about 4 per cent. would be about right. Now, how accurately can the rate of climb be measured? We should expect with our present technique that, by choosing suitable weather and making about five repeat tests in any one condition, that the

chance of repeating the average value on the sixth occasion within 30 ft./min. would be about one in two. This is as suitable a definition of the accuracy of measurement as we can find, and using it together with the figure quoted above means that it will be difficult to fix the all-up weight by means of the rate of climb within 2 per cent.

It has been claimed in America that the present requirements are an improvement on the old C.A.A. requirements, which had a stalling speed limitation, because of the difficulty of accurately measuring the stalling speed. In my view we are in little better position now, and one of the problems that we must face is that of increasing the accuracy of climb measurements. We have done a little work in this respect and I believe that the problem can be solved with appropriate instrumentation: further, the solution will *reduce* the amount of time spent in testing for climb performance and will avoid waiting for extremely good weather conditions.

2.2. LONGITUDINAL STABILITY.

Comparison of P.I.C.A.O. and A.R.B. requirements.

The intention of the longitudinal static stability requirements of both P.I.C.A.O. and A.R.B. is that the aircraft shall have such stability characteristics that if the pilot trims out, and then releases the control wheel, then the aircraft speed will not alter more than a certain limited amount. In order to ensure this, P.I.C.A.O. calls for two requirements:—

(a) that over particular speed ranges about four nominated trimmed speeds (the highest being the cruising speed) the slope of the stick force/speed curve shall be stable and the change of force for any substantial change of speed shall be "clearly perceptible" to the pilot.

(b) that the air speed shall return to within 10 per cent. of the trimmed speed when the control force is slowly relaxed from any speed within the specified range.

The old A.R.B. requirements called for:

(a) stable stick force/speed curves for any trimmed speed in the operating range up to cruising speed.

(b) push forces to hold in the dive when trimmed at the cruising speed.

In interpreting the A.R.B. regulations, A. and A.E.E. have always measured the tab angles required to trim and, to save time, have continued these curves up to the diving speed—and have required that the slope of this curve shall be stable. This is not quite the same as either the A.R.B. or P.I.C.A.O. requirement. This is because of the fact that whereas the sign of the slope of the tab angle/C_L curve is always an expression of static stability, this is not necessarily the case for the stick force/speed curve. This is illustrated in Figs. 5A and 5B. The curve marked aircraft "A" in Fig. 5B represents the type of stick force/speed curve obtained with an aircraft which is statically stable stick free throughout its speed range; this aircraft has a static margin of 0.05 at all speeds and it will be noticed that the slope of the curve steadily increases with increase of speed owing to the effect of the (speed)^2 law on pilot's stick force. Aircraft "B" is also statically stable throughout its speed range, but the static margin increases from about 0.02 at 50 m.p.h. to 0.09 at 400 m.p.h., being the same aircraft as "A" at the trimmed speed. The slope of the curve becomes negative at speeds below 100 m.p.h., in spite of the fact that the aircraft is still stable; in such a case, the P.I.C.A.O. and A.R.B. requirements would reject the aircraft, although it is stable and would be passed by the A. and A.E.E. method. Aircraft "C" again has a static margin of 0.05 at the trimmed speed, but the stability deteriorates as speed increases, becoming neutral at 300 m.p.h. and

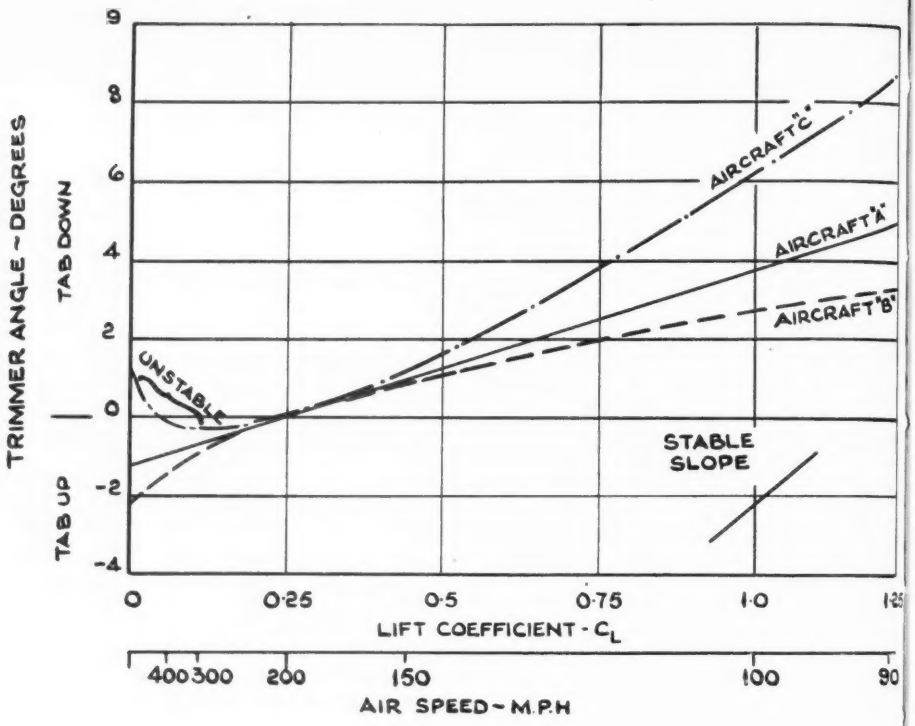


Fig. 5A.
Trimmer angle—C_L curves.

having a negative static margin of – 0.05 at 400 m.p.h. But because of the tendency for force to increase with speed, the slope of the curve remains positive between 300 and 400 m.p.h. In this case, the aircraft will satisfy the P.I.C.A.O. and A.R.B. requirements although it is unstable above 300 m.p.h. and would be rejected on the A. and A.E.E. method (see Fig. 5A).

The interpretation we should like to make is that of true static stick free stability: strictly speaking neither the P.I.C.A.O. nor A.R.B. regulations require this for some region above the cruising speed. This point would be of small importance if the pilot never trimmed above his cruising speed: unfortunately, with high altitude cruising with pressure cabins, which allows large rates of descent in the "let down" from the operating height, the pilots are tending to use higher speeds and also to trim into those speeds (this apparently has been happening on some American airlines in the Constellation). As the diagram shows, it is possible for an aircraft passing P.I.C.A.O. to become unstable under these conditions, and in fact I understand that some complaints have been made of large wandering of speeds from the trimmed speed on certain aircraft.

Since we find the tab trim curves fairly easy to do, and since the information they give to the designer is so useful, we shall probably continue to use them as a quantitative indication of longitudinal stick-free instability, despite their small increase of severity and just check quickly on the P.I.C.A.O. requirements as a line on the friction and restoring forces.

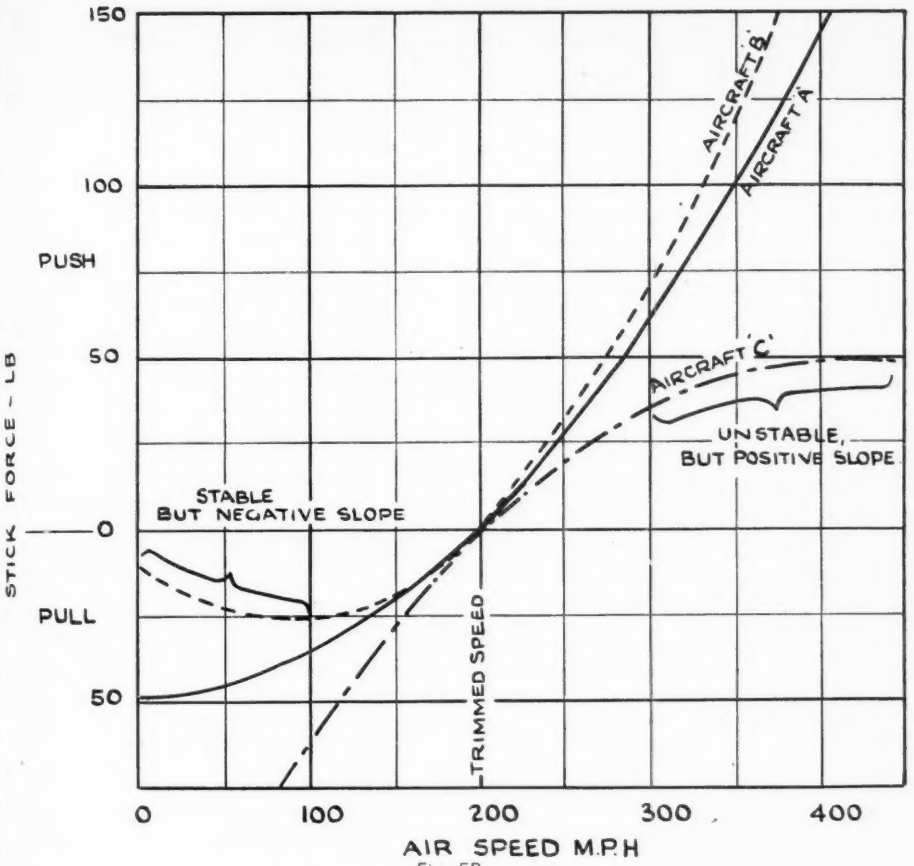


Fig. 5B.
Stick force—speed curves.

2.3. STALLING BEHAVIOUR.

The P.I.C.A.O. and A.R.B. stalling tests call for:—

(a) good stalling behaviour *i.e.*, a gentle roll, if any at all, and retention of lateral control.

(b) stall warning in the form of buffeting etc. at a speed not less than 1.05 times the stalling speed.

(c) that these should be so both engine-off and with a certain amount of power.

The answer to the necessity for these stiff engine requirements is fairly simple. The radio landing aids nowadays envisaged call for fairly flat approaches from some distance away and even before the landing approach, the pilot may be guided by radio through completely blind conditions. Under these kinds of conditions the aircraft is rarely flown under engine-off conditions, so that if stalling is a danger it should be covered under the engine-on conditions.

Is there any evidence that stalling is a serious danger to experienced pilots? A lot of test pilots cannot imagine any experienced pilot stalling an aircraft unexpectedly and quite often they argue that any pilot who does so must be a little "dim." I believe that there have been sufficient cases of crashes caused by stalls of air transports of a certain type, which do not meet the P.I.C.A.O. standards, to show that we cannot dismiss inadvertent

stalling as caused simply by pilotage: it is a serious danger and a danger that can be avoided (or rather signposted) if we demand a stall warning.

The stall warning that is most common with engine-off is buffeting of tailplane and so on, caused by a root stall, or stalling from the inboard nacelles and wing root. Unfortunately, slipstream can clean this up to a large extent, and quite often a mild stall with plenty of warning, engine-off, has turned to a vicious stall, with no warning, above a certain percentage power. Thus the requirement for a stall warning in the form of buffeting with power on is much more severe. It means that the root breakaway must be so intense that application of power will not clean it up. There is a danger that in attempting to meet this requirement the designer may sacrifice so much maximum lift coefficient that he penalises the aircraft's load-carrying performance. Some way has to be found of designing good stall warning features into the aircraft without the undue sacrifice of maximum lift.

Other forms of stall warning besides buffeting may occur—there may be a sudden change of the stick force, a sudden pitch of the aircraft, or a twitch on the ailerons. These might all be acceptable. But we must emphasise that what is wanted is a sudden—a discontinuous change. An extreme attitude, or a heavy pull force or continuous twitching over a range of speeds would not be enough. It has to be something that directs the pilot's attention instantly to the fact that he is entering the region just above the stall. The circumstances under which he is likely to stall—approaching an airfield in zero visibility, and keeping a close look out for unknown obstacles, other aircraft and so on—would need a very marked change in aircraft behaviour to direct the pilot's attention to it.

2.4. Functioning tests.

Under this heading we can include all the functioning and engineering tests on the aircraft which are required before a C. of A. can be recommended and which, from the operator's viewpoint are just as important as the performance and handling tests. We can also include maintenance appraisal investigations which are most valuable for the operator. Unfortunately, we have not yet done a complete series of functioning and engineering tests on a civil aircraft at the A. and A.E.E. This does not mean that we underrate the importance of doing such tests—it has been a matter of first things first. We are in the process of planning and scheduling a test programme to cover all the existing requirements so that perforce some of my following remarks are somewhat tentative. I have included cooling tests with functioning tests and later I shall have something to say on the future of de-icing equipment.

We usually start by checking the starting and run-up characteristics and we make an assessment of the cockpit and crew stations. This means a night flight to ensure that glare and reflections do not interfere with the pilot's vision. For obvious reasons we also do carbon monoxide contamination tests at an early stage. Nothing is done at present on cabin heating since this is not strictly an airworthiness requirement. It would probably be worth while, especially with pressure cabin aircraft, and we could find the relation between the change of outside air temperature and the internal cabin temperature. Noise suppression is another aspect which we have neglected so far and upon which I have strong feelings.

Flight tests are necessary to ensure the satisfactory functioning of flight instruments and special test equipment. At the same time the controls and auxiliary services can be checked both with all engines operating and with one engine out. The times to lower and raise the undercarriage and flaps are recorded as well as times to feather and unfeather the propellers on all engines. These propeller functioning tests show whether the governing

mechanisms are satisfactory under normal flying conditions. A flight of about 15 minutes should be made with at least one propeller feathered all the time; we may find that the oil cooler suffers from coring troubles under these conditions.

We have done little work on the functioning of the electrical equipment in flight. It is foreseen that we shall have to check generator and compressor cooling and such points as whether the battery capacity is adequate for taxying and night take-off conditions with one engine out.

2.5. Pressure cabin tests.

Pressure cabin tests, as such, do not appear to present any special difficulty. We can determine whether the system functions properly up to the maximum required height. Whether one test of this sort gives the full answer I am not so sure. My own feeling is that the pressure cabin is a piece of equipment which is best tested during a properly controlled intensive flying programme. Only in this way can we be confident that the aircraft is free from those irritating, if small, defects resulting from an unreliable cabin system. During the intensive flying we can see whether the pressure cabin is affected by the flight loading conditions and we can pay attention to such items as door seals, and so on. I shall have more to say on intensive flying of civil aircraft.

2.6. Engine installation and cooling tests.

We have not yet attempted any fuel jettisoning tests nor have we done vapour lock tests in flight on civil aircraft. We do cover cooling very thoroughly. As civil aircraft will, in general, be required to operate all over the world, it is essential to ensure that engine operating temperatures will not become excessive even under extreme tropical conditions. This applies equally to the engine-driven accessories, such as cabin supercharger, electrical generators, air compressors and hydraulic pumps.

Maximum temperatures are fixed by the manufacturer for oil inlet temperature, and either cylinder head or engine outlet coolant temperatures, depending on whether an air- or liquid-cooled engine is fitted. A minimum oil inlet pressure is also specified. In addition to this basic information, oil cooler inlet and outlet pressures should be measured to ensure that there is not an excessive pressure drop, temperatures at inlet and outlet from intercooler radiator (if fitted) and fuel consumption, to check that the carburettor is giving the correct mixture strength in flight.

On military aircraft, engine cooling measurements are usually made only on a climb at best climbing speed at maximum climbing power, together with measurements in level flight at the respective full throttle heights in each supercharger gear at take-off, maximum continuous, and maximum weak mixture power. As the civil regulations require that the climb performance be measured both at take-off and maximum climbing powers, with one engine "dead" as well as with all engines operating, cooling tests at these conditions are also made. In view of the emphasis on range for civil aircraft it may also be wise to make tests at the optimum range speed.

The actual flight testing is complicated by the various automatic devices fitted to coolant and oil systems to aid quick starting and to ensure that the engine does not become overcooled in cold weather. Normally liquid-cooled engines have a thermostatic control which prevents the coolant temperature from falling below a set value, either by opening a valve which allows the coolant to by-pass the radiator or else closing slightly the flap at the exit from the radiator duct. With the thermostatic valve in operation it is obviously impracticable to predict from tests made in this country what the coolant temperature will be in tropical conditions. For test purposes the thermostatic controls are made

inoperative and all tests are made with the radiator flaps fully open. It is perhaps worth while noting that since cooling and climb tests are normally made at the same time, the flaps will also be fully open for the performance tests and the rates of climb quoted for I.C.A.N. conditions are therefore slightly pessimistic. The effect of radiator flap opening on range will also be appreciable and the effect of increased opening should be allowed for when estimating range under tropical conditions from tests done in this country.

A further complication is that a part of the coolant may be diverted to provide cabin heating or, as in certain Merlin installations, heating of the charge after passing through the intercooler. In this system, the flow of engine coolant to a subsidiary radiator behind the intercooler is thermostatically controlled so that the charge temperature shall not fall below about 50°C. At the engine conditions at which tests are made there is no coolant flow to this after-heater in the installations so far tested, so this feature can be ignored, although it will be of importance if tests are to be made at maximum range speed. The cabin heating will not be in use normally in tropical conditions, so where this method of cabin heating is employed it should be turned off for the cooling tests.

The oil system also has a similar temperature control device, operated either by oil temperature or viscosity. This is removed when practicable, although in this case there is a danger that the cooler will burst when the engine is started under cold conditions. As this by-pass valve is often set to close at a temperature below the normal operating temperature range, it is frequently possible to make tests without removing the valve. In some cases where it is not possible to remove the valve, and it is suspected that the cooler is being partly by-passed, it may be necessary to do tests under hotter atmosphere conditions. Tests may be further complicated by the fact that oil cooler and radiator are often fitted in a common duct, either as separate units or with the oil cooler mounted behind the radiator or inter-cooler radiator. The air flow through the duct is controlled by a common flap and this may be thermostatically controlled by the coolant temperature. In all cases it will not be sufficient to do tests with the flap fully open as, although full opening may be necessary for adequate cooling, the flap would be in fact partly closed under tropical conditions.

Air-cooled engines usually do not have any form of thermostatic control for cowling gills. Our tests are normally made with gills fully open unless the manufacturer specifies a smaller opening. Here again the corresponding performance figures will be lower than would be obtained on an I.C.A.N. day with the gills in the position for adequate cooling.

Considerable research work has been done at A. and A.E.E. and at Khartoum on the effect of a change of ambient air temperature on engine temperatures. These tests show that while the corresponding changes in coolant and oil temperatures are, in general, predictable within reasonable limits, cylinder temperatures have shown considerable variation and in some cases there has been no increase of cylinder temperature with increase of air temperature. If, therefore, test results, when corrected to tropical conditions by the methods laid down in the P.I.C.A.O. regulations, are over the permitted limitations, it is still possible that cooling would in fact be satisfactory in the tropics and it may well be necessary to test in this, as in all doubtful cases, under actual tropical conditions.

2.7. Maintenance and intensive flying.

From the operator's standpoint maintenance appraisals are invaluable. I think it is true to say that the success or otherwise of a competitive airline is a direct function of the ease of maintenance of the aircraft. Our recent wartime experience has shown how valuable intensive flying tests can be in revealing maintenance and functioning short-

comings and I believe that a strong case could be made for intensive flying tests on civil aircraft. I know that the Corporations do this sort of work at their development units but by that time the aircraft has a Certificate of Airworthiness and it is rather late to reveal an aircraft limitation just as the Corporation is planning line operation.

3. FUTURE DEVELOPMENTS.

3.1. TEMPERATURE ACCOUNTABILITY AND TESTS IN THE TROPICS.

Recent tests have shown us that the P.I.C.A.O. regulations in respect of take-off do not appear to have sufficient margins to cover take-off with one engine failed in subtropical conditions—especially for aerodromes above sea level. There is a rather subtle point here, besides the obvious fact that subtropical temperatures are above temperate conditions. In the P.I.C.A.O. regulations, the take-off climb requirement of 0.035 V_{so}^2 is asked for in a standard atmosphere: *e.g.*, if you are at 5,000 ft. aerodrome, you calculate the performance for 5,000 ft. and 5°C. Now there seems little reason for associating with the air immediately above an aerodrome at an altitude above sea level of X ft., the temperature corresponding to a standard atmosphere of X ft. Fairly obviously there will be a large effect of the presence of the ground on the temperatures and the temperature might be considerably more than those in the standard atmosphere.

Thus at Salisbury, Southern Rhodesia, we have the upper curve of Fig. 6 for maximum daily temperatures, while for Croydon we have the lower curve. You will note that at Salisbury, the "official" standard temperature is exceeded every day in the year, while at Croydon the official standard temperature for sea level of 15°C. is only exceeded 139 days out of 365. Finally, the temperature which is exceeded only one day out of the 365 is 30° higher than standard temperature at Salisbury, while it is only 14° higher than

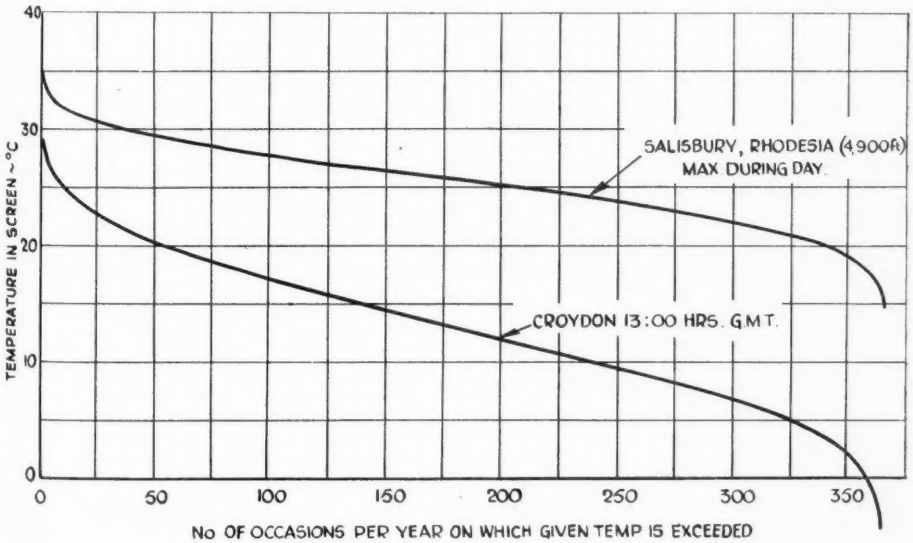


Fig. 6.

Frequency with which given ground temperatures are exceeded.
Daily maximum occurs about 13.00. Daily minimum occurs just before dawn.

standard at Croydon. Thus if we assume we can tolerate, and only just tolerate, the drop of performance which may occur at Croydon one day in 365, then we shall be well below a tolerable level at Salisbury this one day in 365.

To show how important this is, let us think of the DC-3. The present requirements allow it a rate of climb at take-off at sea level in standard atmosphere of 270 ft./min., *i.e.*, a gradient of 2.8 per cent. This falls to 130 ft./min. on one day in 365 at Croydon, *i.e.*, a gradient of 1.2 per cent. This is bad enough—Croydon clearances are barely adequate for this, and this would certainly count as one of the hazards I referred to above. At Salisbury, however, the rate of climb would be negative *i.e.*, the aircraft would not climb at all. I do not know what the clearances are at Salisbury but probably they will not permit the aircraft to be flown downhill.

What the operators could do about this is their affair—they may give the pilot a thermometer to take the air temperature with, immediately before take-off, or we may declare temperatures, based on the kind of diagram we have just seen, for an aerodrome, as well as its geographical altitude. Whatever they decide to do about temperature, it will still mean declaring the aircraft performance over a range of temperatures.

We have methods for correcting the performance of piston-engined aircraft for temperature and at first sight it looks as though all we need is to put this into reverse. However, what is good enough for correction may not be good enough for prediction, especially when payload depends so vitally on the aircraft performance. It may well be, therefore, that actual tests of the aircraft under tropical conditions will be essential if we are to get the accurate information which we all need. This is becoming increasingly true with the more refined reciprocating engines with their many different types of temperature and pressure controls (see para. 2.6 above). How these will affect the performance of the engine under tropical conditions is difficult to foresee, hence actual tests must be made.

This state of affairs is even more true for turbine engines. While we have a beautifully simple method of non-dimensional plotting for the pure jet engine, we have only just touched the fringe of the complications that may exist for the turbine-propeller engine and it will be some time before we can venture to forecast what the effect of temperature will be on performance of these engines. Even for the simple jet we often find that, unless tests are actually made over a wide range of temperatures of pressures, it is impossible to use the non-dimensional methods for predicting performance. Thus, to obtain jet take-off performance at altitudes above sea level it seems absolutely essential at the moment actually to measure the performance at high altitudes— which obviously means using a high altitude aerodrome.

Finally, as indicated above, the establishment of the cooling characteristics of aircraft engines may well demand tests under tropical conditions, with the more complicated systems now being considered.

Thus it appears at the moment as though the trials of civil aircraft may well need to include some tests in the tropics, possibly at both a high and a low altitude aerodrome. Such tests for the long-range civil transport need not involve such a large increase of time on tests as may at first be expected. If a ground organisation with test facilities already exists at some aerodrome in the tropics—and such an organisation is now being planned—then the aircraft under test can be turned out with its own specialist maintenance crew and one or two special technical staff; it can do some tests on the way out and complete a whole series of trials on performance, cooling and take-off inside a week. We should not forget the different weather in tropical countries from that prevailing in England.

3.2. New tests required on turbine-propeller aircraft.

So far little consideration has been given to the effect the introduction of turbine propulsion will have on either requirements or method of test. For a long time—probably five years—there will certainly be no international requirements; and it may be that there will be no national requirements for the special handling problems either. If turbine propulsion introduces any new troubles at all, therefore, we shall have to try to catch them by the general clauses in the handling requirements—and this would give little guidance to designers as to what to avoid.

It might therefore be interesting to see what new troubles we may expect, both on the handling, performance and functioning of turbine-propeller aircraft.

First, we may expect, since the turbine offers us more power for the same weight, that cruising speeds will go up and the problem of control with one engine failed will be more acute. The former will be dealt with in the next section, the latter we can deal with now. We all know that basically the problem of dealing with the control problems associated with engine failure is simply solved by putting on a large fin and rudder. So far the adverse handling feature that has been introduced by the large fin and rudder volume is that of cross-wind ground control— and this can be overcome with a tricycle undercarriage. But can we go on increasing fin and rudder volume? Obviously it will be more and more difficult structurally and spiral instability is likely to be increased in violence. It may well be that a radical solution, like gearing power units together, or mounting engines in the body with extension shafts driving propellers on the wings, may be the answer.

Next there is the "sluggishness" of the simple turbine power unit in responding to changes of throttle setting. The amount of this sluggishness has been much disputed, but even the most fervent advocate of the turbine engine cannot deny that it is there, especially when opening up from very low throttle settings. This disadvantage may be overcome completely on the more complicated power units. Thus, for example, we might think of the "gas producer" plus power turbine-driving propeller as one of these more complicated power units. It is clear that with suitable control systems and propeller this could be made as quick, and possibly quicker, in giving power than the conventional reciprocating engine.

Taking the simple jet as the type of unit which will be with us first, we should anticipate what troubles this may lead us into. Clearly the most important is likely to be the baulked landing case. We shall have to consider carefully what the operating technique will need to be to overcome any difficulty here, and it may be we shall require a greater performance in this condition than that for the conventional reciprocating engine powered aircraft. In addition, pilots may need to be instructed that the turbine speed should not fall below a certain value on the approach and the power should not be cut until the pilot is committed to landing. This will mean, in turn, that the landing distances may well be longer than for those aircraft with conventional power units.

Finally, there will be the new problems of functioning. For civil aircraft the turbine may well be fitted with more complicated control units so that the best compromise between economy of fuel and life of the engine can be reached. Thus control systems working on jet-pipe or turbine wheel temperatures, as well as on turbine speed, may be introduced. Here again, difficulties may well occur in clearing installations for tropical conditions: it may well be that the *only* way of finding how the system will work is by tropical testing. Apart from this, however, functioning trials are likely to be a lot less complicated than with conventional power plants.

3.3. COMPRESSIBILITY EFFECTS.

We are now reaching cruising speeds at which we can begin to expect some compressibility effects to occur, especially with turbine-propelled aircraft. What is likely to be the effect on our test programme? To date, we have usually been content to do our own tests of the handling qualities at some convenient height near sea level. This will not be good enough in the future. Fig. 7 shows, for a typical transport of wing loading 50 lb./sq. ft. and thickness chord ratio of 17½ per cent.: —

(a) How the operating lift coefficient, true speed, indicated speed and Mach number change as the operating heights are increased.

(b) the boundary at which we may expect compressibility effects first to show themselves.

(c) the lowest comfortable cruising speed of $1.5V_{so}$.

It will be seen that the range of cruising speeds between (b) and (c) are cut down enormously at great heights and if such an aircraft is to cruise at 350 m.p.h. T.A.S. at 40,000 ft. the chance of avoiding compressibility effects is small.

Therefore we shall be forced into repeating a number of our more important handling tests over a range of heights—longitudinal stability in particular needing especial attention.

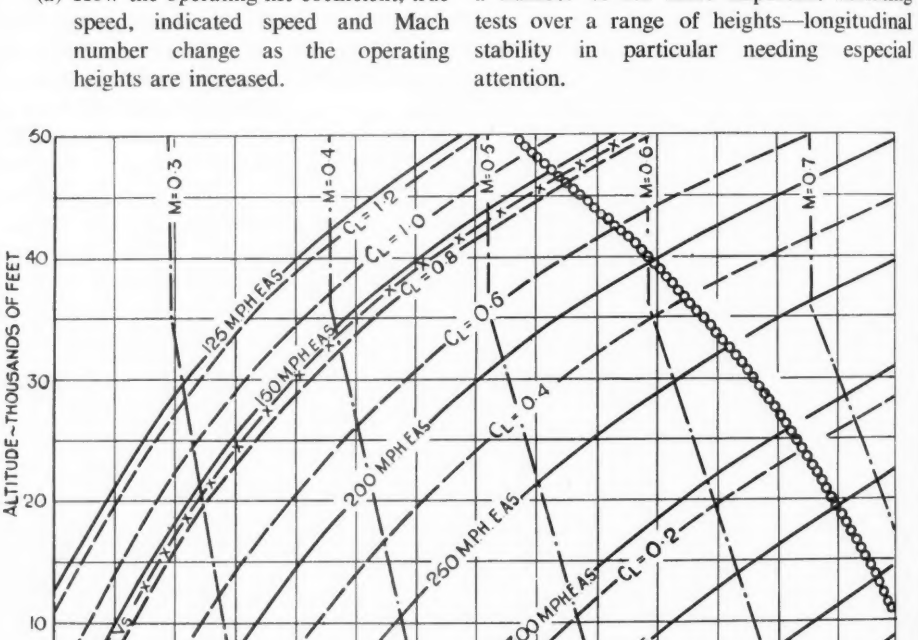


Fig. 7.

Effect of compressibility on high altitude operation of typical transport aircraft.

——————— Constant E.A.S.
— — — — Constant C_L
—— - —— - Constant Mach number
— x —— x — Minimum speed for comfortable cruising, 1.5 V_{so}
oooooooooooooo Critical Mach number for 17½ per cent thickness chord ratio high speed aerofoil

Somewhat akin to this is the problem of determining the minimum speed at which the aircraft should be flown through gusts. So far no tests have been made to determine this speed and the idea behind it is not at all clear. The present suggestion is that it is a speed such that gusts will not stall the aircraft, and so cause loss of control. It is generally accepted that compressibility reduces the maximum lift coefficient, but the trend is not well established and an actual determination of the stalling speed under a variety of loadings and Mach numbers might well be a future requirement.

3.4. De-icing equipment.

The future form of de-icing gear—thermal de-icing—depends for its correct functioning on the correct temperature distribution being obtained in flight. While the fluid de-icer was of rather a "take-it-or-leave-it" type of installation, it is clear that the thermal de-icing system will be built in and designed to each aircraft. Thus there exists, besides the possibility of it being far better than any other type, the possibility of it being far worse than any other type.

We do not want to find out that the de-icer does not work when the aircraft has gone into service and has met with its first bad icing condition. Nor does anyone want to hold up the flight trials while awaiting the occurrence of serious icing conditions. Thus we may have to devise some method of testing the system without waiting for the right weather.

There seem two possibilities. It may be enough to measure the temperature distribution under given flight conditions and, with the background of our research to help us out, to say then that these will give us adequate protection under icing conditions. This would be a simple and easy way out—it might involve considerable instrumentation of a prototype, but the actual flight time would be small. The C.A.A. are seriously considering such tests on prototype aircraft.

Another way might be to create artificial icing conditions in some way (laying water trails by a large tanker aircraft for example) and then flying the prototype into it. This seems to me to be a difficult way of doing the job—and might well be impractical.

Some way of testing de-icing must, it appears, be found and the various possibilities might well be closely studied by the experts in this subject.

4. PLANNING OF CIVIL AIRCRAFT TRIALS.

4.1. Importance of reducing time spent on trials.

It is difficult to over-estimate the importance of reducing to an absolute minimum the time between a new specification being conceived and the first production model going into line operation. If an aircraft type is allowed a total life of about seven to ten years (which does not appear to be much too short), then if the above process takes four years for this aircraft, it is clear that the type is a long way to complete obsolescence before it has done more than two years' service. If another manufacturer can complete the process in two years, then he can afford to start a year and a half later in his design, incorporate all the most recent proved ideas and still beat the other man with a finished model.

Of the four years suggested above it is possible (and it may seem to certain people almost inevitable) that a year or a year and a half will be spent in firm's trials and A. and A.E.E. official trials. If we can divide this by three, or even two, a marked reduction in the elapsed time will occur. For this reason careful planning of the whole of the trials programme pays handsome dividends.

The importance of this was realised at an early stage and a panel was formed at A. and A.E.E. with representatives of the A.R.B., Ministry of Supply, Royal Aircraft Establishment, the operating companies and

the interested firm, to consider the test programme on any particular aircraft at some time in advance of its arrival at A. and A.E.E. This Civil Aircraft Flight Test Planning Panel has performed a useful function in securing an economical use of the flying time on the prototype aircraft.

In the next few sections I should like to put forward some ways in which this can be done, and how certain of these are at present being implemented in the trials now made at A. and A.E.E.

4.2. Division of work between firm and official trials.

One of the most serious ways in which official trials can be slowed down is by sending aircraft for trials in a state in which they are almost certain to be rejected.

It could be argued that in this case the same delay would have occurred whatever the order in which tests are made. In my view this is not so. The delay seems to be increased for the following reasons:—

(a) If the original firm's trials were done according to the requirements, with adequate instrumentation, the trouble would be found in these trials. Official trials could then be limited to spot checks of the more vital points, using the firm's results as a framework of information to cut short the official trials. This would avoid the present wasteful method of making tests at the start which do not give enough information for a lot of flying, following by more adequately instrumented official flights which show up the deficiencies.

(b) "Development" testing at an official establishment may not go as well as at a firm, even with the best will in the world. There is not the particular interest in the aircraft that a firm should have, there is not the design background which will enable alterations to be made quickly and usually there are not the facilities the firm would have.

(c) An important point which the author fears is often overlooked when firms want overtime worked at an official establishment on their particular aircraft is the following:—

If all firms were to ask for this for their aircraft, the consequence would simply be that the official staff would be on continuous overtime, and would spend their time in a series of *Ax* crises. The firms themselves possibly have only two, or at the most three, prototype aircraft going at once: they might therefore deal with *Ax* crises by putting staff on a short burst of overtime. However, this cannot go on for ever: you can do it two or three times a year and possibly it has a revivifying effect on your staff. Do it every month or every week and you will find that *Ax* finally means nothing. Thus if you must have a crisis, you get better results by having it in your own back yard.

The solution seems to be indicated in the point (a) above. The regulations should form the basis of the initial flight trials by the firm. You will find that, correctly done and instrumented, they will give you much useful information to put things right. You will be fairly sure already when the aircraft goes to the official establishment that it will be satisfactory and you will know that long delays because of the interpolation of "development" work will not occur.

4.3. The planning of the trials.

In Appendix I, I have shown how one flight test programme can be tested under five main headings covering engineering functioning tests, handling, performance, take-off and landing and engine and oil cooling. In addition we have the preliminary ground tests. As most of the flight tests have to be made at

more than one loading our working schedule can be modified suitably; Appendix I is a typical trials plan for civil aircraft recently tested at the A. and A.E.E. It should not necessarily be taken as a guide as to the priority of the various tests. We use our judgment in the light of weather and so on as to what tests we do on any particular day and it is our aim always to do as much as we can on any one flight. For example, we might do engineering tests during the same flight as we do cooling and consumption tests. I cannot emphasise too strongly that one of our essential tasks is to ensure that by careful planning we reduce to a minimum the time necessary to complete our Certificate of Airworthiness tests.

4.4. INSTRUMENTATION.

The instrument position should now be improving and we have been pleased to find our latest prototypes well equipped with full instrumentation and automatic observers. The author's view certainly is that the more records we take, the more safeguards we have if things go wrong. Thus, all the records would not in general be analysed; in fact, probably only half those taken could be analysed with the present staffs: but if some trouble arose, the relevant films could be sorted out and looked at rapidly.

Full instrumentation of prototypes is therefore another way of ensuring quick flight trials. There will be no disturbing hold-ups while new instruments are hastily fitted to deal with an unexpected trouble—in fact, it might not even be necessary to make special flights if the relevant instruments have been working during the whole of the trials.

4.5. OTHER AIDS TO RAPID FLIGHT TRIALS.

Besides full instrumentation, there are other ways in which the firms can help to speed up the flight trials.

One of the simplest of these is suitable water ballast tanks, if possible with intercoupling tanks and electrically-driven pumps. With suitable arrangements of these, it should be possible to do stability tests over a full range of C.G. positions and loads without relanding. This would speed up enormously the tests, as it is well known that unserviceability occurs much more frequently with the aircraft on the ground than it occurs in flight. Thus the more that can be done (within the limits of the pilot's endurance, that is) without relanding, the faster the tests.

There are other possibilities, as yet unexplored, which might have the same effect. We have not yet got to the stage where we take up a flight hostess and cook to serve dinners and generally entertain the flight personnel while doing the tests, but this may well occur with our bigger and better aeroplanes. Prototypes should supply some few of the necessities of life in reasonable comfort.

5. CONCLUSION.

I have attempted to cover the present position in flight testing of civil aircraft and the probable future changes.

It seems clear that quick testing, which we all want to see in flight trials, can only be attained by close collaboration beween firms and the official testing establishment and by the firms taking over more and more of the routine tests as time progresses.

Better understanding of the purpose and the interpretation of the various tests will aid in this and I will be glad if I have helped at all to this end by the present lecture.

I would like to record here the help given me by the staff at A. and A.E.E. in preparing this lecture, particularly to Mr. J. C. K. Shipp of the Civil Aircraft Test Section, and Mr. D. Fraser, late of the C.A.T.S.

APPENDIX I

Typical Flight Trials Plan

Part I— C. of A. Tests

Test	*A.R.B. reference*	*P.I.C.A.O. reference*
Section I (Ground Tests)		
Determination of weight and C. G. position	A.10	
Calibration of instruments		
Measurements of static friction in aircraft control circuits	D.28	2.4
Compass deviation		9.4
Section II (Preliminary—convenient light load)		
Preliminary familiarisation and air test		
Preliminary assessment of general handling qualities both with symmetric and asymmetric power		
Preliminary assessment of behaviour and speed at the stall		
Section III (Functioning etc.—convenient light load)		
Starting and run up characteristics		
Assessment of cockpit and crew stations	D.10	4.2, 4.3, 4.7, 4.8, 7.7, 8.2, 8.3
C.O. contamination	A.16	4.11
Functioning of instruments and special test equipment ...		
Functioning of controls and auxiliaries	A.16	4.2, 4.3
Functioning of essential services—all engines		
ditto —engine out	D.7	8.3
Feathering of propellers	D.7, D.23	7.2, 7.3
Functioning of fuel system—general		7.4
ditto —vapour lock test	D.13	7.4
Fuel jettisoning	D.13	7.4
Functioning of de-icing—wings, tail, propellers	D.16	7.3
ditto —engine	C.7	7.8
Pressurisation tests—heating and ventilation	D.22, D.30	4.12
Power plant vibration	C.4	5.1
Section IV (Performance—convenient light load)		
Static P.E.C. determination by aneroid and trailing static methods		8.3
Pitot P.E.C. determination by venturi pitot method ...		8.3
Section V (Handling—critical loadings for forward and aft C.G.)		
Taxying or shimmy tests	D.19	2.6, 3.4, 4.6
Determination of stalling speeds	D.5	2.3

APPENDIX I—*continued*

Test	*A.R.B. reference*	*P.I.C.A.O. reference*
Ability to trim and short period dynamic behaviour—3 axes—all engines		
Longitudinal control—change of trim with flaps, undercarriage and power		
Longitudinal stability and control behaviour		
Lateral control—turns on one control and steady straight sideslips—all engines		
Lateral control—turns and sideslip—engine out ...		
Behaviour at low speeds, at the stall and during recovery—straight flight—all engines		
Behaviour at low speeds, at the stall and during recovery—straight flight—engine out.		
Behaviour after sudden engine failure		
Determination of minimum control speed V_{mc} (air) ...		
Controllability during baulked landing—engine out ...	D.1, D.5	
Minimum speed for straight flight—engine out	D.5	
Ability to trim—3 axes—engine out		
ditto —two engines out (as required)		
Take-off and landing in cross wind	D.1	2.6
Section VI (Performance—full load)		
Ceiling climb—en route—all engines	D.1	2.3
Check climb—en route—engine out		
ditto —take-off—engine out		
ditto —baulked landings—all engines		
ditto —approach—engine out		
Section VII (Take-off and landing—full load, aft C.G.)		
Distance to clear 50 ft. screen—all engines	D.1	2.3
Distance to 50 ft. screen and determination of minimum control speed V_{mc} (ground and near ground)—engine out		
Accelerate-stop distance and determination of critical point—engine out		
Landing distance—powered approach—all engines ...		
ditto —engine out ...		
Section VIII (Engine and oil cooling—full load)		
Engine, oil and accessories cooling—climb—all engines	D.24, D.40	7.5, 7.6, 7.8
ditto —level flight—all engines		
Engine, oil and accessories cooling—climb—engine out		
ditto —level flight—engine out		

APPENDIX I—*continued*

PART II—M. OF S. ACCEPTANCE TESTS

Test	*A.R.B. reference*	*P.I.C.A.O. reference*
Section IX (Performance—full load)		
Fuel consumption and speed power tests—all engines ...		
ditto —engine out ...		
Range flight (including night flying)		
Section X (Miscellaneous—convenient light load)		
Noise and vibration		
Temperature and humidity control		
Radio calibration and performance		
Navigation calibration		

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DISCUSSION

Mr. E. T. Jones (A. and A.E.E., *Fellow*): Mr. Hufton had made it clear that the number of tests had increased considerably since before the war and had drawn the conclusion that the overall tests on prototypes would occupy from 12 to 18 months nowadays, *i.e.*, the tests by the manufacturers and the official flight testing station. His own opinion was that tests on the easy types should occupy only about six months, but he supported Mr. Hufton's view that the testing of the large, and possibly difficult, types should occupy 18 months, no matter what was the policy.

In suggesting that aircraft should remain at the makers' works until the makers had developed it to the acceptance standard of the A.R.B., Mr. Hufton was presupposing that each firm had three runways of adequate width and adequate length to be able to test all their aircraft up to full load, including all the engine cut take-offs. Most people would agree that hardly any of the aircraft manufacturing firms in this country had runways long enough to be able to do that. He advocated the opposite policy in the case of the more troublesome types and the large types of aircraft; the makers should keep the aircraft at their works or aerodromes until it had been proved airworthy and then the official testing station and the makers should collaborate as far as possible to do one set of tests between them.

The author had not made it clear whether the Air Division of P.I.C.A.O. was likely to accept a lower degree of safety in take-off in hot countries, or whether it would demand the same degree of safety there as elsewhere. If the latter, how did they propose to achieve it?

The author had drawn the conclusion that on especially busy airports they could expect to have one accident per 10 years. He believed that the statistics from which that conclusion was drawn were those relating to military operations both in America and in this

country and he would have thought that in civil airline operations statistics they should be able to see much better figures than that. He disagreed with the author's suggestion that they might plan to accept, say, one accident per 10 years per airport, and urged that they should plan to avoid accidents altogether. Those aeroplanes which behaved badly at take-off in a cross wind or the like should definitely be restricted from flying from the airports when there was a cross wind of more than a given velocity.

Did Mr. Hufton consider that the engine cut take-offs made in daylight provided any proof of the safety of an aircraft at take-off when an engine cut out at night, or should engine cut take-offs actually be done at night?

Mr. A. E. Woodward Nutt (D.C.A.R.D., Ministry of Supply, *Fellow*): When the formation of the Civil Test Flight at Boscombe Down was proposed nearly two years ago it was not welcomed wholeheartedly; there was a feeling abroad that the official Certificate of Airworthiness tests and the firm's initial tests could be left to the firms themselves and the A.R.B., and the subsequent testing could be done by the operators. During the past two years, particularly because of the efforts of the Civil Test Flight, that opinion had changed and the tendency nowadays was for more and more work to be done at Boscombe Down. He was not sure that that tendency was not going too far, and it would be one of the tasks of the Civil Aircraft Flight Test Planning Panel, of which he had the privilege to be Chairman, to try to maintain a proper balance.

He endorsed strongly Mr. Hufton's remarks on the whole-hearted co-operation between all the parties on that Panel; it had indeed made a tremendous difference in dealing with the testing of civil aircraft.

Another aspect of the duties of the Civil Test Flight at Boscombe Down to which the author had not referred, but to which he had contributed a great deal, was the fundamental testing to provide the technical ammunition necessary to keep their end up at the P.I.C.A.O. and other conferences. That would assist in the introduction of International airworthiness requirements which would be neither "unintelligible nor unworkable," to use the lecturer's own words.

As to the importance of reducing the time devoted to the trials of civil aircraft, he agreed entirely with Mr. Hufton in so far as flying time was concerned. But they must be careful not to cut down the development time for a new civil type of aircraft by taking short cuts when some fundamental change was really needed, because of political or other pressure to get a new aircraft quickly into use on air routes.

There was an essential difference between the testing of a civil and a military aeroplane. With the military type it was permissible to accept an aircraft into service when certain matters still remained to be put right. The Service could cope with development, and modifications could be introduced; further, the Service was prepared to take an element of risk. But they must do all that was humanly possible to ensure that the civil aircraft was right before it got into the hands of the operators.

He had always been sympathetic with the idea of intensive flying, but it was difficult to fit in. It seemed that such intensive flying must be contemporaneous with the flight testing and that unless there were extra prototypes, for which someone had to pay, this was difficult. Would Mr. Hufton suggest how it could best be fitted into the testing programme?

If a warning of stall were provided, was it necessary for the stall itself to be gentle? It might be argued that, if there were an unmistakable warning, the aircraft should never be stalled. Again, what form should the warning take? They would not like to suggest adding another warning light to the constellation already existing on the flight deck, or another noise to the cacophony

already there; perhaps the author would suggest sticking a pin into the pilot!

In spite of shortage of staff and lack of airfield facilities and accommodation, the Civil Test Flight at Boscombe Down were succeeding in building up a reputation similar to that which Boscombe Down had enjoyed for some time in connection with military aircraft, for impartiality and thoroughness in testing. The motto printed on their Christmas cards was: "Civil Answers to Civil Questions."

Mr. N. E. Rowe (British European Airways, *Vice-President and Fellow*): The author had concentrated his remarks on the tests that were made to satisfy the A.R.B. regulations for airworthiness, which he supposed could be construed as showing that the aircraft was safe to operate ordinarily and was safe under any conditions of emergency which could be foreseen. No doubt the author felt, as he did himself, that such tests must be related to the need for safety. But it was extremely important also, in making the tests, as the work proceeded and as aircraft changed in their general form, that that work should be related to standards that were adequate, whether those standards were written, or whether they were the current standards accepted internationally but not completely written down; conversely, they must not ask too much by reason of their ignorance of what was going on. It was so easy to play safe on paper and definitely to curtail what might reasonably be done, and so lose the advantage that might be taken of new things. They looked to a testing establishment such as that at Boscombe Down to "vet" current standards from that point of view.

Boscombe Down had always enjoyed the reputation that it had the advantage of first-class pilot's opinions. He had had the privilege of being Chief Technical Officer there some years ago and had kept in close touch since, and he had always regarded the personnel there as forming a living standard of what they must have in regard to the qualities of aircraft, as distinct from those standards which could be written down quantitatively. It was important that on the civil aircraft side they should continue to have that living standard; they must be sure always that they had the best opinions, otherwise the conclusions drawn were not the best that could be drawn. He suggested that periodically outside opinions should be consulted by the testing establishment; and he would spread that practice internationally. There was possibly a risk in interpretation, for one nation might handle things differently from another, to the detriment of international standards.

He did not think that they had achieved the same degree of definition of required standards for stability and control in civil aviation as they had in military aviation. It was important that they should do so and the work of the team at Boscombe Down was likely to lead them to that position most quickly.

Safety nowadays depended a great deal on the qualities of stability and control, and especially on the qualities of aircraft which affected pilot fatigue. They had done a great deal in the course of the years to tighten up on those engineering factors which had caused accidents; but there was always the risk of what was called "pilot error" and, as Air Marshal Cochrane had pointed out during a recent lecture to the Society, often it was the aircraft that was blameworthy, and not the pilot. The pilot was being asked to do too much, and he felt that the problem of stability in flight, the lack of which was possibly one of the major causes of pilot fatigue, should be given the closest attention.

Attention should be given to their standards of stability and control in low speed flight in the worst conditions of visibility, and when landing on occasions when the ground was visible only at the last moment. Indeed, stability and control must

be studied carefully under all conditions of flight, including the use of automatic controls, because he believed automatic controls were likely to be used widely, including use in let down and landing. It was important that the pilot should be given full confidence in his aircraft. He would feel far less fatigued if he knew he had an aeroplane which, even in rough weather, he could leave practically to fly itself, in complete confidence, instead of having to release the automatic control and fly the aeroplane himself, feeling unhappy about the whole thing all the time.

Mr. Woodward Nutt was absolutely right when he had said that a civil aeroplane must be ready to work regularly when it was put to use, for several reasons; it must earn money, it must replace aircraft then operating, and it must be as good in that sense as any fully-developed aircraft which might have been operating on the route for some years. It was essential, therefore, that there should be a protracted period of development for a new civil type, so that if things went wrong in the early days they could be discovered and put right before the aircraft went into service. The work during that period should be done mainly by the makers, in collaboration with the potential operators. Possibly during that time also, they could make some of the tests which had to be made for airworthiness; and he would have thought that pilots from the testing establishments could join in then, to learn something about the aircraft and appreciate some of the difficulties.

He was in some doubt as to whether an aircraft should be proved fully airworthy before it went to the test establishments. Inasmuch as so many factors depended on pilots' opinions, it was important that the test pilots should have some opportunity to fly a new type quite early in its life, without being asked to commit themselves, so that if there were a snag in regard to flying qualities which they considered important, the makers could be told.

Mr. W. Challier (Rolls-Royce Ltd., *Associate Fellow*): There were two ways of countering the reduction of take-off performance due to adverse weather conditions; one was to increase engine performance, and another was to restrict the weight of the aeroplane. Possibly the increase of engine performance would be the better and more economical way and this could be done by using liquid injection, such as water or water-methanol. The quantity of liquid required was obviously proportionate to the time of injection and this time should be reduced to the absolute minimum which was considered necessary. This was particularly important in the case of jet-propelled aircraft for which the rates of injection were high.

The period of five minutes for which the engine was cleared at take-off rating had always seemed to him to be rather long and to involve an unnecessary weight penalty if the amount of liquid to be carried was based on it. Would it be possible to reduce the time during which injection would be used, and did the author consider that 2½ to 2 minutes, or even less, would be sufficient to satisfy the new requirements?

Mr. W. Tye (Air Registration Board, *Fellow*): The question of intensive flying had been raised by the author particularly in relation to pressure cabin tests; but he was sure that he realised fully its value in many other respects. The Certificate of Airworthiness procedure as they knew it at present, whereby an aircraft was subjected to a prescribed list of tests, failed to pick up the 101 small, but nevertheless important, ways in which an aeroplane could fail in actual service conditions. Possibly the only solution was to introduce some kind of accelerated service test. Recently the Civil Aeronautics Board of America had introduced into their national regulations a general requirement which permitted the Civil Aeronautics Administration to require intensive flying trials; and it was understood

that the C.A.A. had in mind a duration of the order of 150 hours.

The present procedure for flight testing in conditions such as those in which an aircraft would eventually go into service, as, for instance, in the tropics, was an inheritance from the pre-war I.C.A.N. arrangements, and it was not very satisfactory from the point of view of proving the qualities of the aircraft in operations under the conditions it would experience in all-the-world flying. The Certificate of Airworthiness at present implied that the aircraft was safe in "normal" conditions. In future he thought it would be necessary to state, either in the Certificate of Airworthiness or in the Manual, the particular conditions in which the aircraft had been proved to be safe—for flying in the tropics, for flying in icing conditions, for flying by night, and so on. If they had to state that the aircraft was safe to fly in certain conditions, then it was hard to see any alternative but to make tests in those conditions. That would seem to add considerably to the length of time required for conducting trials and led to a consideration of ways and means of reducing the actual time occupied in the trials, even though more hours of actual flying might be required.

One of Mr. Hufton's views was that the manufacturer of an aeroplane should carry rather more responsibility than he had done in the past. In view of the present difficulties of lack of man-power and lack of equipment, which had necessitated the setting up of the Civil Flight Test Section at Boscombe Down, this seemed to be the only possible immediate solution. But he felt that Mr. Hufton was right in his view that the Flight Test Section should in the course of time see to it that the firms themselves carried more and more of the general load of work, reducing to the absolute minimum the check flying to be made by the centralised flight test establishments. He looked forward to the time when the responsibility for the flight testing work would be delegated to the manufacturers, to the same degree as it was at present in the case of all other aspects of airworthiness.

Mr. M. B. Morgan (Royal Aircraft Establishment, *Fellow*): The aerodynamics people were being landed with an impossible task in meeting requirements in respect of engine cutting nowadays, and he would like to pass the game back to the engine manufacturers. From the stability and control angle it meant that in order to meet those requirements they had to put on fins about the size of a house, and then they were promptly in difficulties when taking off an aeroplane in a strong cross wind, and so on. It was part of his job at the R.A.E. at Farnborough to "sell" big fins, and he did this with a certain amount of distaste.

In the case of the four-engined aircraft they did not budget for two engines cutting on one side, but only for one engine cutting on one side, feeling that the likelihood of two engines cutting on one side was so remote that it could be forgotten. That gave rise to the question of probabilities. Surely, by careful design, particularly careful accessory design, engine manufacturers should strive to ensure that in the future the likelihood of one engine cutting on one side would be as remote as was the possibility of two engines cutting simultaneously on one side to-day. If something approaching this could be achieved, they would be able to throw away the specialised take-off technique, and have much smaller fins at the rear end.

Mr. R. S. Stafford (Chief Designer, Handley Page Ltd., *Fellow*): The aircraft constructor had been struggling for too many years against the handicaps imposed by the unreliability of engines. Additions had to be made to the aircraft, particularly in fin surface, by the awful engine cut conditions, and it was time there was a new approach to the problem.

The initiation of feathering was an operation which was denied to a pilot until after he had climbed through 50 ft. It was

another additional burden, in that propeller drag was assumed always to be present after the engine had cut. Did Mr. Hufton consider that the restriction thereby imposed was justifiable, and could he state on what real evidence it was based?

Having had some experience of organising flight trials, and in particular of trying to find that elusive factor called "position error," could the author hold out any hope that they could get away from the rather lethal practice of flying aircraft a few feet from the ground, just above or just below hangar top level? Further, could they reasonably expect to measure position errors near the stall without the need to hang out from the aeroplanes torpedo-shaped objects, which invariably ran amok when they were being drawn back into the aeroplanes after they had done their job? Some interesting possibilities had been mentioned for finding position errors by radio-navigational means. Had the author studied them, and did they hold out any hope that they would assist in the solution of the problem?

Mr. F. Radcliffe (Handley Page Ltd., *Fellow*): One impression which might be gained from the lecture was that they were merely trying to meet a list of regulations rather than trying to make aeroplanes airworthy; in that connection the responsibility was a joint one between the constructor, the operator and the airworthiness authorities. Until all three pulled their full weight, they would be producing aeroplanes to comply with a certain system of regulations, but which eventually would not be altogether the ideal aeroplanes for service.

Recently he had visited a B.O.A.C. development flight. There an aeroplane, having obtained its Certificate of Airworthiness, was given an intensive flying test over a period of about 350 hours, over a route which embraced different temperatures and climatic conditions, and it was only then that snags were revealed which the meeting of regulations had failed to reveal. That was why he urged that they must temper their regulations with a certain amount of practice and eliminate many academic tests, substituting something much more practical. Until they did that the clearing of a machine would occupy 18 months, whereas the period could be reduced to something much nearer 6 months.

Mr. J. O. Doley (Portsmouth Aviation Ltd., *Assoc. Fellow*): He was disturbed by the references made to the clearing period of 18 months for a large type of aircraft. The design of such an aircraft would occupy some three or four years and if they were to add another 18 months to that period, then by the time the production models were put into service they would be even more out of date than aircraft sometimes seemed to be nowadays. It was a courageous manufacturer who would go ahead, without substantial Government backing, to produce a number of aircraft until the major parts of his test programme had proceeded satisfactorily.

He was not clear as to how the 18 months period was spent, whether it represented mainly flying time or the time devoted to analyses, on the ground, of the results of flights. If the latter, he did not think they could do much about it, beyond increasing staffs. If flying time were the trouble, he had in mind that in this country aircraft were grounded for considerable periods from time to time because of bad weather; he wondered whether, if they had also to consider tropical conditions, they should be driven to do flight testing in countries where the climate was more favourable to providing a greater number of flying hours in a given period. Would Mr. Hufton make more clear the relative amounts of flying time and ground work during the test period?

Mr. G. R. Edwards (Vickers-Armstrongs Ltd., *Fellow*): He had been impressed recently by the fact that test flying, both by the firms and the flight testing stations, had

largely got into the tradition of testing the airworthiness and the performance of aeroplanes under agreeable climatic conditions, with blue sky and sunshine; from such tests there emerged aeroplanes which, under those conditions, were reasonably satisfactory and reasonably safe. It was not unknown, however, that an aeroplane which had passed such a test had later given evidence of undesirable characteristics, when subjected to the rigours of airline operation. The plea that the existing schedule of testing be increased could not be denied. Mr. Radcliffe's practical approach seemed to be the right one. Many of the things which went wrong, in his experience, were not those which the Boscombe Down station tested in their particular line of business. The radio would go wrong; there were conditions in which the pilot could not see ahead, or possibly he might be submerged in ice. Such conditions were not envisaged in any of the regulations. There might be a general statement that an aircraft should be capable of being handled under certain conditions; but an aeroplane could only be proved reliable in those conditions by really making it work in them. Evidence could be found that an aeroplane behaved well in bad weather and icing conditions only by testing it in those conditions. It was a long and painful business, but it had to be done, because it was unfair to pass on to the operators aircraft which were not fully tested.

If all these things that should be done were done, the work would occupy three years. The aeroplanes might have to be taken all over the world in order to find the appropriate climatic conditions.

He was almost inclined to stop there and to say, "and so, what!" But he would endeavour to be constructive. One means of expediting the tests was to get all the people together in the first place, and to have on board representatives of the A.R.B., Boscombe Down and Farnborough, when the first tests were made, provided the firm had demonstrated that the aircraft was safe and airworthy previously. If an aeroplane did something peculiar at that stage, no one should be ashamed of it; anybody who ever did anything at all had done something wrong sometimes. If mistakes were made in public, there was no need to be ashamed, so long as they were honest effects or mistakes such as anybody was likely to make.

There had been no reference to stick-fixed stability. Inasmuch as the A.R.B. regulations referred to stick movement in addition to stick forces, it would be some comfort to some people to know that the revised regulations merely demanded stick-free stability. He had been amazed to hear Mr. Morgan say that he did not agree with large fins, for he had thought Mr. Morgan was going on to say that he did not agree with large tailplanes!

Mr. C. G. A. Woodford (English Electric Co. Ltd. *Assoc. Fellow*): He emphasised the great need for increased instrumentation; the Fedden Mission had raised the matter on returning from America four years ago, where they had found over 140 people engaged on instrumentation test flying at the Boeing Aircraft Company.

Although during the war great strides were made in the official establishments in this country to build up the technique, much still remained to be done in getting each large unit of the Aircraft Industry on to its own feet to enable much instrument work to be done. Now that the war was over, there should be greater effort to make more instrumentation equipment available to the aircraft firms.

Sir Frederick Handley Page (*The President*): He was not sure that a period of 18 months, or 12 months, could be regarded as a long period for the testing of a new type of aircraft. After all, when he introduced a new type of motor car a motor car manufacturer made a number of secret trials on the road, covering a long period in order to

ensure that the vehicle would prove satisfactory to the ultimate customer. Careful testing was necessary also in the case of an aeroplane. It was quite unreasonable to expect that an aeroplane would be absolutely right when it came out of the works, bearing in mind what an extraordinary amount of development technique there was behind aeroplane design and manufacture, as compared with that applying to any other type of industrial vehicle at the present time.

Everyone in the Aircraft Industry in times past had claimed that he should have greater freedom because, given greater freedom, there would be greater progress. They had seen the devolution of inspectional duties, formerly made in detail by the A.I.D., and now done by the manufacturers, so that in effect the only supervision was that which might be called a psychological supervision as to the adequacy or otherwise of the organisation and the character of the organisation of each firm's inspection. The same process had taken place in regard to design, and now, thirdly, in regard to the testing of aircraft.

With the greater freedoms that had been given to manufacturers and designers there must be greater responsibility also. This meant that the aircraft manufacturers, when presenting a new type to be recommended for its Certificate of Airworthiness, must be able to present it in such a form that there was a *prima facie* case for the granting of the Certificate without much trouble. Therefore, the manufacturers themselves had got to do a great amount of testing in their own development units before presenting the aircraft for an official test with a view to recommendation for a Certificate of Airworthiness. There were a number of aerodromes in this country with long runways, not only concrete, but grass runways, providing opportunities for making tests not necessarily under official supervision. If the manufacturer were to be given the freedom he had claimed, he must accept the responsibility of not having his hand held all the time in order to be guided through trials, and so on; he must do that development work before submitting his aircraft to an official test for the Certificate of Airworthiness. There was no better place where he should do that work than on his own aerodrome, where there were facilities for working at all hours of the day in order to make modifications, repairs and 101 other things.

It was necessary, in the case of a civil aircraft, not merely to ensure that it was airworthy. They had to make the aircraft airworthy to the extent that it was an instrument operable by the purchaser. If the purchaser, after accepting delivery, had to make many development trials, many modifications, and things of that sort, then he was justly annoyed, because he had spent his money and in return had not received earning power.

He felt that it was necessary to make these comments because people did not realise that, with the endeavour of the Air Registration Board organisation to give greater freedom, there must be an acceptance of greater responsibility by those who built and sold aircraft.

Did Mr. Hufton consider that the testing of civil aircraft would be advanced if they had available a few expert consultant test pilots? In the United States, there were several people who were engaged as professional consultants and test pilots; and provided their standard of piloting technique were sufficiently high, and their standard of professional etiquette were also sufficiently high so that they did not discuss everybody else's machines with competitors, it might be that from their wealth of realised experience the manufacturers might obtain a good deal of help in bringing out a new machine.

Wing Cdr. E. Coton (*Associate*) *contributed*: Did the Civil Flight Tests include engine cuts on the ground well below Va. to see if a pilot could, in practice, prevent a

ground loop whatever the speed might be? It seemed to him that with a conventional, *i.e.* unstable undercarriage, it was quite likely that a ground loop was inevitable if the cut occurred within a certain speed range. .He had heard that a DC-2 was safe in this respect, but certain military types were not, and perhaps some civil types might not be.

Steering nose wheels would seem to be a standard fitting on future civil types, and he suggested that they made possible a much simplified take-off technique which would need only 50 per cent. or so of the existing rudder power while requiring no sensible increase in runway length, and retaining the same degree of safety. The aircraft was merely held three wheels down until the best practical asymmetric climbing speed was reached, and rudder power was provided to cope with critical engine cut at this speed.

A full discussion on such a technique would lead to long arguments on air drag of undercarriages, induced drag at unstick speed, wear and tear on wheels and so on, but he could not think of any disadvantage which would outweigh the reduction of rudder power it would allow. And what a reduction in testing time! (50 per cent. based on a climbing speed of 120 knots, and a minimum control speed of just under 90 knots with present technique).

Take-off safety figures should be obtained, finally, near the ground because the physical conditions were different, and because the behaviour of the aeroplane could be much better observed with the ground as a close range datum. No further advantage would be obtained by repeating the test at night; the test pilot would merely be trying to imagine himself as the airline counterpart of P/O Prune. Perhaps a test pilot should try it for the sake of the experience, but not as a test of the aircraft. The users must be the authority in a case of this sort. In fact, should not line operation be a final C. of A. test, and should the aircraft therefore be given first a proving period as a freighter?

Mr. D. M. Jameson (Air Registration Board) *contributed*: The following comments were made in a purely private capacity.

He supported strongly the measures advocated for the reduction in the total time required for completing official trials, but did not share the pessimism regarding the results which might be obtained by employing them. Using substantially the procedure advocated by Mr. Hufton, the C.A.A. claimed to have completed their part of the official trials of two four-engined civil aeroplanes in about 30 hours flying each. In comparing this 30 hours with Mr. Hufton's 60-80 hours, the following considerations should be borne in mind:—

The United States requirements of that date were stabilised, and in consequence there was available an established flight test practice related to them, with which both the firms and the test establishment were familiar.

It was at present necessary to schedule performance data for *at least* two sets of operating rules.

Considerably greater attention was now being given to functioning tests.

Modern requirements in the United Kingdom were, in some matters, more realistic than their American counterparts, and this advantage in itself might entail a slight increase in the flight test time required.

The United States weather was more propitious for flight tests.

These considerations made Mr. Hufton's estimate of flying hours less pessimistic than it would at first sight appear, but he felt that a target of six to nine months for this flying (20 minutes per day) was, to put it mildly, unambitious.

A sufficiently clear distinction did not seem to have been made between the following three aspects of the problem of static longitudinal stability:—

The conditions of power, speed and configuration for which positive static stability should be required; the way in which the requirements should be expressed; and the way in which the aeroplane should be tested in order that the A.R.B. might determine whether or not it complied with the requirements in the form in which they were expressed.

The first two aspects were under discussion at the moment for the purpose of incorporating both the P.I.C.A.O. standards and the experience gained in the application of U.K. standards during the past two years. In this country the civil practice was to phrase requirements as far as possible directly in terms of what the pilot actually wanted, regardless of the classical definitions of stability, since this should be least likely to lead to difficulties of interpretation for unorthodox aeroplanes; this led, *inter alia*, to stick force movement requirements in connection with stick-free static longitudinal stability. An alternative approach would be to phrase the requirements in terms of, say, static margins, and to couple them with arbitrary requirements relating to the mechanical characteristics (*e.g.* friction, elasticity, lost motion) of the control system. Such an approach might be difficult to apply directly to small aeroplanes in which the trim might be accomplished by a spring loading device, and in which facilities for test instrumentation might be limited; or to large aeroplanes embodying power-operated controls.

With regard to the third aspect, he would agree that, where tabs were fitted, the method of measuring tab angles against speed should be acceptable for demonstrating compliance with current B.C.A. requirements, provided that the tab power, the elevator balance characteristics, and the mechanical characteristics of the control system were shown to be such that a satisfactory β-C_L curve automatically resulted in satisfactory stick force/speed curve at, and close to, each of an appropriate series of trimmed speeds. For testing against P.I.C.A.O. acceptable practice, the production of stick force/speed curves, directly or indirectly, seemed to be essential.

In connection with Figs. 5A and 5B he suggested that aeroplane "B" probably would *not* be rejected and that aeroplane "C," if its maximum cruising speed greatly exceeded 200 m.p.h., probably *would* be rejected; these suggestions being on the basis of current B.C.A.R.s which referred to *small* deviations from a trimmed speed within the limit stated.

Mr. R. P. Dickinson (*Associate Fellow*) *contributed*: The lecturer said that the A.R.B. (or the P.I.C.A.O.) requirement of longitudinal stability was that on release of the stick the airspeed should not wander much.

It would appear that this was not a logical definition of stability since if it were it would not be possible to obtain trim curves on an unstable aircraft; such curves could, in fact, be obtained and the lecturer had showed an example of them. He would be glad of the lecturer's views on this; also did he not agree that some better standard of stability should be the requirement, *e.g.*, a static margin of at least X per cent. (stick free) must be present under all conditions of flight?

The lecturer said that although they tested for the failure of all the power on one side in the case of a twin-engined aircraft, they only tested for the failure of one engine in the case of a four-engined aircraft. What were the lecturer's views on the choice of two or four engines from the point of view of probability and seriousness of engine failure? What were his views on the scheme of having twin fins offset in opposite directions so that on losing the slipstream effect on one (due to engine failure on that side) a rectifying couple was automatically applied to the aircraft?

The lecturer made little mention of the jet engine. Did he agree that the consequences of an engine failure should be less serious in the case of the pure jet than for the reciprocating engine (or even turbine-driven propeller) of the same thrust, because:

(a) The units could be so much closer inboard;

(b) There would be no slipstream to lose and hence less tendency for a wing to drop.

MR. HUFTON'S REPLY

Mr. E. T. Jones: He had indicated in the lecture that he thought that the time for completion of C. of A. trials from the firm's first flight was now somewhere between 12 to 18 months. He still believed that, if all went reasonably well, this could be cut down to between six to nine months by careful planning and co-operation between firm and A. and A.E.E. He emphasised again that these figures were for firms' tests and official acceptance tests for C. of A. and assumed no major troubles.

He was not recommending that the firm should undertake all the tests. Obviously, for the reasons indicated by Mr. Jones, the firm might well be unable to do full load trials. If the firm did tests to C. of A. requirements at light load, the A. and A.E.E. could complete these as required at the heavy load, and they should benefit enormously by the results the firm had obtained. Co-operation in the trials at low weights would be needed, there would be no question of repetition of tests unless they met any anomalies in the tests at high weights.

No decision had yet been taken by P.I.C.A.O. as to whether they were trying

(a) to reach a certain minimum level of safety for world operation of airlines

or (b) to reach the same minimum level of safety for operations in any country, whatever the climate.

This was to be discussed at a special meeting of P.I.C.A.O., together with the question of whether practicable methods of obtaining the second aim could be devised. Various methods had been proposed, varying in complexity of operation from actually measuring the temperature prior to take-off, and adjusting the weight to that temperature, to dividing the world into, say, arctic, temperate and tropical zones, and having the aircraft load adjusted for operation in these three zones.

The figures for engine failure on take-offs in America was that quoted to him for civil airline operation before the war; it did sound high and he hoped that Mr. Jones was right and that it would be shown to be too pessimistic.

He realised when quoting a figure for accidents that the proposal would look cold blooded, but it was now, he believed, an accepted airworthiness principle that you could not design for a zero accident rate—but only for a low one, which would be continually reduced towards zero as the years went by and further experience was gained. One way, for instance, of improving the figure he had quoted would be to reduce the power/weight ratio of the aircraft. This could only be done at any given time in the history of aeronautics, by either making more take-offs and landings per passenger mile, or by cutting down on ancillary safety equipment such as radio and so on. Either of these would *increase* the accident rate per passenger mile from other causes than engine failure. At this given time, therefore, they must strike a balance between the accidents due to the various causes so as to reach a minimum value. He hoped the figure he had quoted above was not too far from this optimum. In five years' time they might have gained enough experience, in all forms, to be able to propose another, better, figure.

On the question of engine cut take-offs at night, they could argue that, with civil aerodrome illumination as it was now planned, the pilot would be given enough visual cues to make engine cut take-offs at night as safe as those in the day. Certainly they should not try to do engine cut take-offs on an inadequately lit runway.

If an engine cut while the pilot was trying to take-off in a mist, or a blizzard, which cut

down visibility even with aerodrome lighting, then he must agree that their tests were barely applicable. But should they try to cover this double contingency?

Mr. A. E. Woodward Nutt: He agreed that trying to rush through tests, which were essential to safety, from political or other causes, would eventually be fatal to their prestige in aircraft construction. But they must be certain that they were doing only those tests which were essential—they should revise the requirements repeatedly both from the point of view of *necessity* and *sufficiency*. If they asked for too many tests, there was a grave danger of some essential ones being skimped because of the pressure of time.

Intensive flying was a difficult problem. Certain aspects of troubles which occurred were certainly connected with airworthiness, others were more maintenance and servicing problems, and problems concerning the economical running of aircraft. Thus operating companies were vitally concerned in the intensive flying, and it would reduce the value of any intensive flying if they were not brought well into the picture. On the other hand, a central testing body had the possibility of collecting valuable information for a wider variety of aircraft. It might be possible to fit in the intensive flying on the aircraft doing the C. of A. work, extending the flying to give the required total number of hours in the required atmospheric conditions. Thus a trip to the tropics and back to do C. of A. trials there would involve 36 hours of routine flying. If this were to be done, it was clear that the prototype would need to be nearer the final production aircraft than they usually were at the moment.

In his opinion, it was still better to have a good stalling behaviour, even with a stall warning. A gust might, for instance, cause a stall before the pilot could react to the stall warning. Similarly, just before touch down, the pilot might deliberately ignore the stall warning in making the touch down, and a bad wing drop might be dangerous.

Mr. N. E. Rowe: The alternative method of making intensive flying trials could certainly work and might be better than the one suggested above, but it involved a second prototype.

As he had indicated in his reply to Mr. Jones it would not be necessary for the aircraft to be checked completely for the C. of A. at the firm, particularly at the higher weights, but the tests made at the reduced weights would give full confidence that the major snags had been overcome before it went to A. and A.E.E.

Mr. Challier: Some change in take-off rating had been considered at P.I.C.A.O. and many nations were in favour of such a scheme. He was not sufficiently expert to discuss the merits more deeply.

Mr. Stafford: Full discussions on the policy regarding feathering of the propeller on the dead engine had taken place at the various P.I.C.A.O. meetings. The argument in favour of the present stringent requirements was that the ability to make a successful take-off after engine failure did not depend on the pilot pressing a feathering knob immediately the engine cut. It was argued that the pilot would have his hands (and his feet) full during this critical period, and should not be expected to have to press another knob as well. If the duty were delegated to the second pilot, or engineer, there was grave danger of confusion (awful examples of the results of delegation of major duties in emergency were cited to them). There was the further point that the pilot might not wish to feather until he knew the engine was beyond hope. Obviously these arguments would not apply to automatic propeller feathering.

Methods of making position error measurements were being reviewed now at A. and A.E.E., but he could promise little hope of change in the near future. The possibilities were radar methods, C.W. methods (*e.g.* Decca Navigation System), formation flying with a calibrated aircraft, and development

of a high speed suspended static head, with automatic winding drum.

Mr. Radcliffe: Most of the present requirements had certainly been found necessary to provide a certain basic level of airworthiness. He agreed that operational methods also contributed a large part of the overall safety. The present P.I.C.A.O. airworthiness regulations were intended not only to see that the aircraft was basically airworthy, but also to supply reliable data on which operations could be based.

There were more sides than one in the second query raised by Mr. Radcliffe. He would only like to say that the problem now appeared to be one of demonstrating that individual production aircraft did not differ too far from the aircraft (usually the prototype) on which C. of A. tests were made. In his view the case actually supported the present requirements, as far as airworthiness tests were concerned. There were, of course, other troubles not connected with airworthiness, but they could hardly expect flight tests essentially designed to demonstrate airworthiness to show these up as well.

Mr. Doley: He believed that, generally speaking, with the present staff, working out of results just fitted into periods of unserviceability of the aircraft, weather and so on. He would not like to split up the various reasons for delays at this stage, since their experience was limited. He had prepared a diagram showing how time was lost in a particular case, but he had been advised that it might be considered libellous and had therefore withdrawn it. In the written text of the lecture he had indicated various methods of improvement, and he was optimistic about the results.

Mr. Edwards: He was gratified to hear that "many of the things which went wrong were not the things which A. and A.E.E. tested." This was an argument for increasing the regulations and the testing that was done.

Like all new subjects, aeronautics suffered growing pains. Regulations were subject to them as well, and too often they found some completely new disease for which they had not tested. The only way out was, clearly, to demonstrate that the aircraft was completely airworthy as far as all the things they knew about were concerned, and then do quick check flights in a range of operational conditions (during intensive flying possibly) to see that no new trouble had arisen. He did not think this would add appreciably to the length of testing.

He regretted that he might have misled Mr. Edwards as regards stick-fixed stability. P.I.C.A.O. regulations did not call for this, but the old A.R.B. regulations did. Whether the new A.R.B. regulations would still have them was a matter which might cause considerable argument in the near future.

Mr. Woodford: He thought the official sections responsible for "Instrumentation" had done a very good job in difficult circumstances. There was still a lot more work to be done—they had now the necessities of test flying and they should have the luxuries if they wanted to speed up testing and analysis.

Sir Frederick Handley Page: The Chairman's remarks on testing said what he had wanted to say a great deal better.

He thought there was a lot in the idea of consultant test pilots—but would have it a combined team of test pilots and a few technicians of the highest quality. They could be hired by firms at fairly high rates to check their aircraft. If the firms had to pay a high price for their services, they might value the information they gave more highly than some they got gratis from official bodies. The fact that they would be independent of the firms would be an excellent feature.

Wing Cdr. Coton: Testing for ground loop after engine failure at low speeds was already included. The pilot was allowed to cut the other motors, apply full rudder and all differential braking. Tests at A. and A.E.E. had shown that delay in reacting to engine failure might have dangerous consequences to the undercarriage. This might be almost as

bad on a tricycle aircraft as on a conventional aircraft, unless the tricycle had a steerable nose wheel.

He would not like to agree altogether to Wing Cdr. Coton's second suggestion and actually the runway had to be big enough to take the accelerate-stop distance as well, and this might be increased by his technique. However, it might well have advantages on very high powered aircraft.

Mr. Jameson: He could not agree that all the present flight requirements of A.R.B. could possibly be done in 30 hours, starting with no knowledge of the aircraft. If he considered only checking of information supplied by the firm, then this might well be true. This, he thought, must be the meaning to be attributed to the C.A.A. statement.

An average of 20 minutes' flying per day for test work was actually very good, when judged against the best A. and A.E.E. did during the peak effort of the war. Obviously the figure would vary from month to month, but the best flying hours for a year were about 115 hours per aircraft. Daily this gave about 20 minutes per aircraft. The seasonal fluctuation was from about 12 to 30 minutes per day per aircraft.

This figure was, if anything, a high value for purely airworthiness testing on prototypes since it was based on a much wider type of trial, including armament trials and intensive flying, which did not need such good weather; and was also obtained for a fleet which included a fair proportion of production aircraft. The latter one was less likely to go unserviceable and the spares situation was usually better.

If the figure was to be improved they must:

(a) find out how to do more tests in indifferent weather, or find better weather.

(b) improve serviceability.

(c) improve maintenance and spares position.

Mr. Dickinson: His own view on longitudinal stability was much closer to that of Mr. Dickinson than to that of the P.I.C.A.O. regulations. They had to operate the requirements as they found them and try to lead P.I.C.A.O. into the path of grace. There were, clearly, loopholes in the present regulations which would let through borderline aircraft that might show wide variability from aircraft to aircraft in production.

Fairly obviously it was easier to meet the regulations for a four-engined aircraft than for a twin, at the moment. But he felt that there were strong reasons for requiring different levels of performance for aircraft having different numbers of engines, on account of the different probability of engine failure, and these might well be debated at further meetings of P.I.C.A.O.

He believed that offset fins had been tried for reducing the effect of engine cutting, but that these had not been too successful—why, nobody knew.

It seemed clear that jet-propelled aircraft should have lower minimum control speed than conventional powered aircraft for the reasons stated. How far these could be offset by the increased thrust for take-off which might be available, remained to be seen.

THE ROYAL AERONAUTICAL SOCIETY

The 712th Lecture read before the Society on 24th April 1947 at the Institution of Civil Engineers, Great George Street, W.1. In the chair, Sir Frederick Handley Page, C.B.E.
Mr. R. B. Farmer deputised for Dr. Drinkwater, who was unable to be present

THE PREVENTION OF FIRE IN AIRCRAFT

by

W. G. GLENDINNING, B.A.

and

J. W. DRINKWATER, D.Phil., B.Sc., Wh.Sc.

Mr. Glendinning joined the Chemistry Department of the Royal Aircraft Establishment in 1917. *His early work was concerned with fabric testing and research until* 1929, *when he started work on the causes of fires in aircraft and methods for the prevention and extinction of such fires. From* 1937 *to* 1940 *he was employed on liquid de-icing systems. Since* 1940 *he has worked exclusively on research problems connected with fires in aircraft.*

Mr. R. B. Farmer, who deputised for Dr. Drinkwater joined the Royal Aircraft Establishment in 1939 *in the Engine Department, working first on flame damping, high altitude testing and the use of bi-fuels. Since* 1943 *he has been working on aircraft fire problems.*

INTRODUCTION

A Fire Prevention Sub-Committee of the Aeronautical Research Council published its findings in 1922. At that time the major risk was from crash fires in which the fuel was ignited by the engine either directly or indirectly through the medium of oil, wood, fabric or dry grass. Preventive measures recommended included crash-proof tanks, with a suggestion that these should be carried on the wings; fire-proof bulkheads; fire-proofing of inflammable materials; cooling of exhaust pipes; and fire-proofing of magnetos. Fires in flight were usually in the carburettor and a successful carbon tetrachloride extinguisher was designed at the Royal Aircraft Establishment and tested in flight by the late Squadron Leader Norman. However, the weight of the system, about 35 lb. per engine, was considered excessive and the action recommended was to turn off the fuel and dive the aeroplane.

In 1924 the United States Air Corps staged a large number of full-scale crash tests with the object of studying the factors leading to fires on crash. These tests showed that the exhaust was the main danger and that the fires often originated inside a broken manifold. Laboratory and full-scale tests at Farnborough in 1929 confirmed the danger of complicated and fragile exhaust systems.

The Royal Air Force in 1938 adopted an automatic engine fire extinguisher operated either by flame switches or by an inertia crash switch. A similar system was also made a requirement for civil aircraft.

Early in the war the Chief Inspector of Accidents started an investigation into the causes of aircraft fires which were taking a heavy toll of training and operational aircraft. This work formed the basis for the experimental work on the prevention and extinction of engine fires which was done at the Royal Aircraft Establishment.

Simultaneously, work was started at Farnborough on fires caused by enemy action and on methods of prevention and extinction.

The main subject of this paper is the

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prevention of aircraft fires, which in its widest sense includes extinction before the fire becomes dangerous to the safety of the aircraft and its occupants. The evidence, from which the causes of accidental fires were deduced, was mainly obtained from non-operational military flying so that the conclusions reached are applicable to civil aircraft.

The subject is discussed in the following order:—

(1) Accidental fires in flight.
(2) Crash fires.
(3) Fires caused by enemy action.

ACCIDENTAL FIRES IN FLIGHT

A fire in the air is perhaps the most disconcerting type of fire and one which, during the war, was considered very important on account of the psychological effect it had on the crew. It was for this reason that research was done to reduce this hazard and to find ways and means of combating the fires. Today, civil flying is uppermost in our minds and fires in the air are not expected to be so frequent as they were during the war when enemy action was a contributory factor. Nevertheless, the danger is still there and the measures taken to reduce this hazard during the war are still applicable today.

The consequence of fires in the air are frequently disastrous, involving loss of life and the complete destruction of the aircraft. Hence the prevention of such fires is essential, although as a safeguard effective measures for the extinction of such fires, should they occur, are necessary. Whether the fire develops slowly, following a minor failure such as a fuel or oil leakage from a pipe or union, or rapidly following a major failure, the result is usually the same. The fire spreads to the fuel and oil supply lines and this is often followed by damage to the airframe. The aircraft controls may also be severely damaged as a result of fire and this may lead to loss of control of the aircraft. During the war many cases are known whereby the collapse of a wing occurred in less than one minute following the first appearance of a fire.

In the early stages of the war the losses in personnel and material experienced by the Services because of aircraft fires were so heavy that the Chief Inspector of Accidents was asked to pay particular attention to the fire aspect of air accidents. The whole matter was carefully considered and incidents were divided into three categories:—

1. Fires in the air.
2. Fires in aircraft standing on the ground.
3. Crash fires.

Of these, fires in the aircraft standing on the ground were of the least importance because life was seldom endangered and immediate steps could generally be taken to deal with the outbreak. In addition it was found that in the majority of cases, the fires could be attributed to incorrect starting or shutting down and probably could have been avoided if adherence to the proper procedures had been maintained.

In 1942 it was decided to concentrate on the problem of fires in the air and a concerted attack was made by the Chief Inspector of Accidents, The Ministry of Aircraft Production and The Royal Aircraft Establishment. This work proceeded on a high priority throughout the remaining years of the war and it is gratifying to those engaged on the problem to know that a considerable number of the recommendations put forward as a result of this work, were effective in securing the safe landing of aircraft after the occurrence of a fire. To know that a fire can be extinguished is not sufficient and the ultimate aim must be to prevent the occurrence of, and secondly to limit the spread of, fires in the air and this rests to some extent with the aircraft designer.

An attempt is made in this paper to put forward recommendations for the prevention and limitation of fires in aircraft. These recommendations are based on the examina-

tion of aircraft in which fires have occurred, some of which have resulted in crashes, others in which the aircraft have made safe landings, together with the results of work conducted at the R.A.E. and elsewhere.

CAUSES OF FIRES IN THE AIR

Before proceeding to a detailed discussion of the design features of aircraft fire precautions it is essential to analyse the causes of aircraft fires.

The results of this analysis, although prepared from evidence collected during the war can apply to a large extent to present conditions, because most are based on the examination of fires in non-operational aircraft, in which fires could not be attributed to enemy action. The investigations often exhibited weaknesses in design which could sometimes be remedied by suitable modification action and in any case be avoided in the future. In general the main causes of accidental fires in the air may be attributed to the following:—

1. Engine failure.
2. The electrical system.
3. Auxiliary equipment, for example the oxygen system.
4. Electrical causes external to the aircraft electrical system.

It is clear that a fire could be started easily from any of the first three causes as a direct result of enemy action.

Of the above causes the one caused by the failure of the engine is without doubt the most important and will be discussed in some detail.

In a review of this kind it is obvious we must learn from experience and therefore most of the remarks and recommendations relate to piston engines because, during the period under consideration the statistical data were collected when the piston engine was used almost exclusively. Towards the end of the war the turbine engine was used to a small extent but sufficient evidence is not available to allow a thorough analysis to be made of the possible causes in the same way as for the piston engine. However, where the power unit can be isolated from the aircraft and whether it houses a piston engine or a turbine, a large number of the general recommendations as regards fire prevention apply; furthermore, it is reasonable to assume that the lessons we have had in the prevention of fires with the piston engine, especially during the war years, will form a most useful background in the application of the turbine engine to aircraft of the future.

In view of the many recent forecasts about turbine engines in civil aircraft taking about another five or even ten years before they are in regular use on our airlines, it is perhaps not too late to hope that some aircraft with piston engines will embody all the known precautions to make air travel as free as possible from the fire hazard.

ENGINE FAILURES

By far the most important cause of a fire in flight is a major mechanical failure. There is no evidence to show that what in the past were known as carburettor fires are frequent in the air, although they are by no means uncommon on the ground.

Again in order to base the facts on experience, our remarks apply mainly to British type engines, although the full-scale experiments made at the Royal Aircraft Establishment included an American air-cooled radial engine. A description of these particular tests will be given later.

Comparing the radial air-cooled engine with the liquid-cooled in-line engine it is difficult to say, with any degree of certainty, which type is the less vulnerable as regards fire risks because there are so many variables to take into account when considering the pros and cons of each type. The statistical data, however, produced by the C.I. Accidents Branch indicate that a larger proportion of accidents, caused by fires in the air, occurred with aircraft fitted with air-cooled engines. No doubt this can be partially

explained by the increased difficulty experienced in extinguishing a fire in an air-cooled engine, because of the large air flow assisting the fire and at the same time reducing the effectiveness of the extinguishing liquid. Taking into account enemy action the reverse is more than likely and tests have shown that air-cooled engines can continue to run for many hours after one or more cylinders have been pierced by gunfire, whereas the liquid-cooled engine would probably fail and catch fire in a comparatively short time, mainly as a result of the loss of coolant.

Considering the piston engine, the factors leading to a mechanical failure vary widely. In the poppet valve engine for instance, there have been several fires which, on investigation, have been attributed to tappet locknuts slacking off and altering the valve setting. This in turn has caused, in the case of liquid-cooled in-line engines, the burning of the flame traps leading to an explosion in the induction system. In some cases inlet valve failure has been a contributory cause of fire.

In other instances a shortage of oil has resulted in a mechanical failure, causing bearings to become overheated which ignite any remaining oil in the system.

AIR-COOLED RADIAL ENGINES

When a mechanical failure takes place in an air-cooled radial engine, such as the failure of one or more connecting rods in the articulated assembly, the tendency is for the fractured rod or rods to be forced through the crankcase periphery causing the displacement of one or more cylinders. With the conventional layout of this engine, with a branched induction system from the supercharger casing and a collector type exhaust ring (Fig. 1), the displacement of a cylinder cannot occur without causing a rupture to the induction and exhaust systems. A failure of this kind (Fig. 2) occurs under

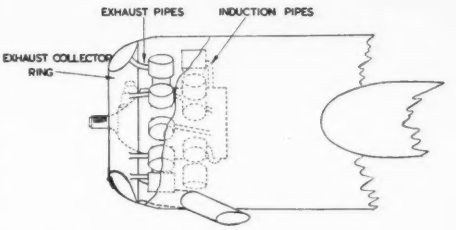

Fig. 1.
Typical radial engine with exhaust collector ring at fore end of engine.

high power conditions and, immediately the rupture takes place, a jet or jets boosted air-fuel mixture and hot exhaust gases are emitted from the fractured induction pipe and adjacent exhaust branch pipes. In addition, hot lubricating oil will escape from the crank case.

This was a typical kind of failure during the war but it is not easy to state whether the fire originates by the hot exhaust gases igniting the boosted fuel-air mixture or

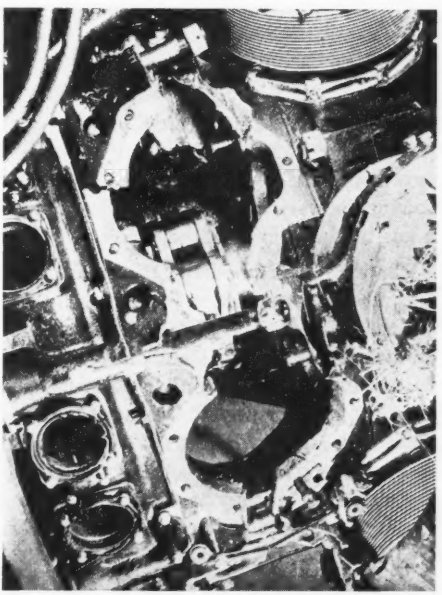

Fig. 2.
Air-cooled engine failure.

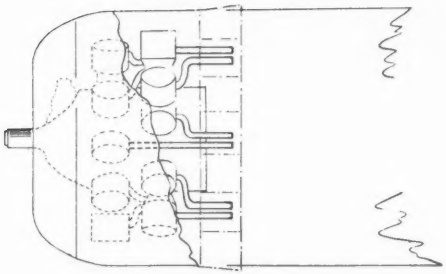

Fig. 3.
Typical air-cooled radial engine with single ejector exhausts.

whether the hot lubricating oil ignites on the hot surface of the exhaust manifold. The full-scale tests at the Royal Aircraft Establishment, to which reference has already been made, indicate that the lubricating oil is probably the most likely source and explains the occurrence of fires without the presence of boosted air-fuel mixtures. It is also obvious that the intensity of a boosted mixture fire is governed, among other factors, by the degree of throttle opening.

A boosted mixture fire is extremely fierce and resembles a large blow lamp and can burn through the aircraft structure in a very short time. Fires of this nature have been known to cause the failure of the wing structure of various types of Service aircraft in less than one minute.

Mention has been made of the collector type of exhaust system. Until recently this was the usual design of exhaust system for air-cooled radial engines but during the war the question of flame damping and exhaust glow suppression was important and this initiated a large amount of development work on new exhaust designs. Some designs of the flame dampers and the anti-glow shields increased the fire hazard but others were a distinct improvement. Of the latter kind the single ejector exhaust system (Fig. 3) is a notable example and towards the end of the war this system was adopted for many engines both here and in the U.S.A. This single ejector exhaust system has a higher noise level than the collector type system and may not find favour for civil aircraft.

LIQUID-COOLED IN-LINE ENGINES

Statistics indicate that the risk of fire on a liquid-cooled in-line engine is somewhat smaller than on a radial air-cooled engine. In addition to the absence of a large air flow through the engine nacelle, the difference is attributed to the fact that the induction system is not adjacent to the exhaust system and in consequence a major internal mechanical failure in the engine does not as a rule inflict damage to these particular components.

Shortage of coolant has been found to be the cause of many fires. The trend of events

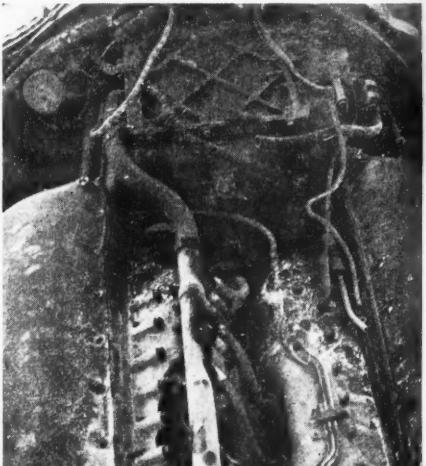

Fig. 4.
Liquid-cooled engine failure.

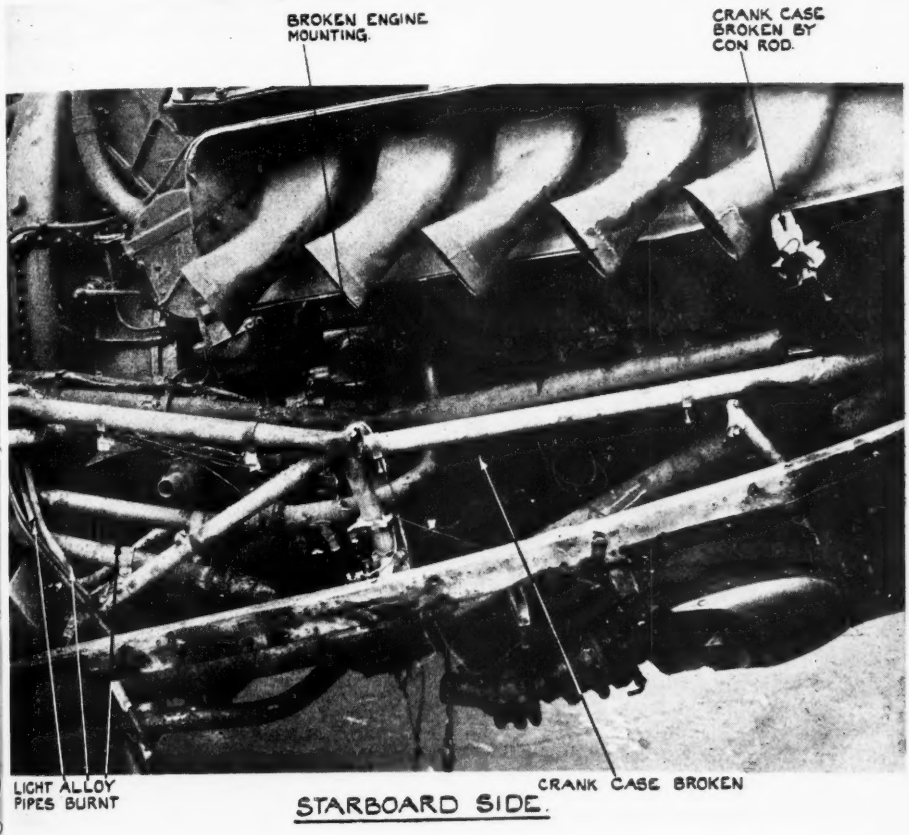

Fig. 5.
Liquid-cooled engine failure.

in failures of this sort are obvious in that they usually lead to induction pipe fires if a complete engine failure has not already occurred.

Figure 4 shows an engine which caught fire in the air and which the authors were able to examine. In this particular case the pilot was able to make a reasonable crash landing, thus allowing a thorough investigation to be made. The examination showed that an intense fire had been raging in the induction system and was attributed to a shortage of coolant, which in turn was caused by the loss of the coolant header tank filler cap. Fig. 5 shows an example of another fire which occurred in the air after which the pilot managed to make a safe landing. This fire was attributed to the failure of No. 2 connecting rod and the seizure of the big end.

In British liquid-cooled engines the coolant itself is not a source of danger when used in the proportion of 70 per cent. water and 30 per cent. glycol. The use of 100 per cent. glycol is, however, a source of danger. Experiments conducted at the Royal Aircraft Establishment showed that glycol heated to 130°C. and allowed to drip on to a

plate at a temperature of 430°C. ignited instantaneously.

As a result of the analysis of a number of accidental air fires it became clear that an immediate change was necessary in the pilot's drill of vital actions to deal with a fire. The drill then in use had been evolved as a result of fires occurring in the carburettor intake. It consisted of closing the fuel cock on the affected engine and opening the throttle fully in order to suck the flame into the engine and at the same time empty the carburettor float chamber. With a displaced cylinder, this results in highly boosted air-fuel mixtures leaking from the damaged induction system. In addition the supply of hot oil from the damaged crank case continues to feed the fire while the propeller is still rotating. This indicated that the first step which should be taken is to stop the engine and minimise the supply of hot combustible fluids to the fire. In consequence the vital actions were changed to the following:—

(a) The crew to prepare to abandon the aircraft or, if at too low an altitude, take up crash stations.
(b) Close the throttle.
(c) Feather the propeller, or if not a feathering type select minimum r.p.m.
(d) Turn off the fuel.
(e) When engine has stopped, or if rotating slowly, switch off the ignition.
(f) Operate the fire extinguisher.

The suggestion that the fire might be blown out by diving, side-slipping, and so on, was also cancelled for two reasons:—

(a) Recovering from a dive increases the wing loading at the time when the structure may have been weakened by fire, and
(b) An increase in speed may increase the intensity of the fire, particularly if engine components are constructed of magnesium alloy.

At the same time warnings were issued that no attempt should be made to restart the engine, as the fire may recur, and that fuel should not be jettisoned while there is a fire in any part of the aircraft.

DIRECT FUEL INJECTION VERSUS CARBURETTOR

It is opportune at this stage to refer to an engine design feature common to air- and liquid-cooled engines which may tend to reduce the fire hazard in flight, especially as regards boosted mixture fires. This concerns the use of direct cylinder or port injection in place of the carburettor system. Throughout the history of the piston engine there have been numerous discussions on the advantages and disadvantages of the two systems of fuel metering. During the war years all British and American engines were fitted with the carburettor system. The Germans on the other hand used direct cylinder injection but unfortunately they did not collect information on fires. In any case a comparison between the Allied and German experience would be rather dangerous.

Comparing direct port injection with the carburettor system it could be stated that the injection method offers considerable advantages over the carburettor system, especially as far as fires in the induction system are concerned.

Another advantage, and an important one for the direct fuel injection system in connection with the fire risk aspect, is the ability to use a low volatile fuel, sometimes called a "safety fuel." This aspect is discussed in more detail later.

AMERICAN RADIAL AIR-COOLED ENGINES

Experience by the C.I. Accidents in the investigation of fires in aircraft fitted with American engines has not been so extensive or varied as for British engines. It can, however, be stated that where a fire has occurred in an American aircraft because

of a mechanical failure it has started in much the same way as on British engines.

On American engines it is usual for the exhaust collector ring to be situated at the rear of the cylinder assembly in a semi-buried position (Fig. 6). Comparing this position with the one usually adopted for the British engine it is considered that the temperature of the exhaust collector ring in this rear position will always be several degrees higher than it would be in the exposed position at the front.

This major difference in design prompted the inclusion of a typical example in the fire tests at the Royal Aircraft Establishment.

Investigations of a number of fires on certain types of American aircraft during the early stages of the war did, however, disclose a number of deficiencies in installation design, just as similar investigations exhibited many undesirable features in British designs.

TURBINE ENGINES

The turbine engine for aircraft propulsion is in its infancy; in consequence there is no large store of evidence available similar to that on the piston engine, to enable a good analysis to be made of the causes of accidental fires in flight or fire accidents due to enemy action.

The few instances of accidental fires occurring in the air which it has been possible to investigate have been caused either by the mechanical failure of a high pressure fuel pipe, or a bearing failure. Aircraft have caught fire from the above two causes, but have been brought safely to earth again only because the pilots have shut off the main fuel supply as soon as they have suspected something wrong with the engine and not because they have known the engine to be on fire.

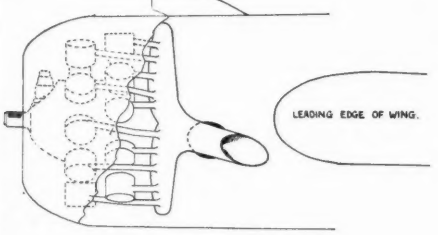

Fig. 6.
Air-cooled radial engine with rear exhaust collector pipe.

Fig. 7.
Meteor I. Fire damage to port nacelle.

In one case the pilot of a Meteor was in difficulties trying to control his aircraft, unaware that one of his engines was on fire until he was informed by radio by another pilot flying nearby. The pilot in the Meteor immediately turned off the appropriate fuel supply and made a safe wheel-down landing. In this case the Accidents Branch were able to make a thorough examination of the aircraft; this revealed that the front and rear bearings of the turbine had failed, allowing the cooling air vanes to foul the magnesium intermediate housing which resulted in a fire. Fig. 7 shows the damage to the engine and engine nacelle as a result of this fire which, it is estimated, lasted for about four minutes.

This example and others emphasise the need for a reliable detection device so that the pilot can take the necessary action before it is too late.

Failures of the high pressure fuel pipes leading to the spray burners in the combustion chambers (Fig. 8) have caused serious

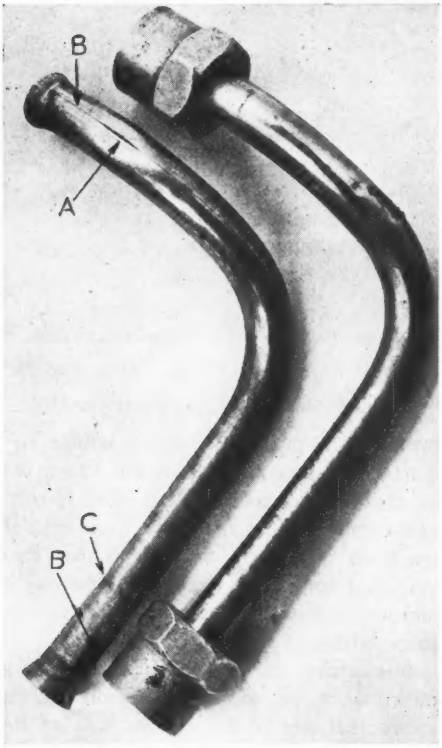

Fig. 8.
Fuel pipe failure.

fires in the air. The source of the fire, when a fuel pipe fails adjacent to, or near to, the combustion chamber, needs no elaboration for it is clear that a spray of fuel impinging on the hot surface of the combustion chamber will readily ignite. In this connection kerosene is probably a little more dangerous than petrol on account of the lower open spontaneous ignition temperature of the kerosene. An indication of the surface temperatures of the various components in a typical gas turbine engine is shown in Fig. 9.

From the foregoing remarks it might be stated that the most probable sources of accidental fires in the air with turbine engines may be:—

(1) A bearing failure, which in turn would probably result in displacement of the rotor.

(2) The leakage of fuel or oil which may be ignited on the hot surfaces or by flames from a damaged combustion chamber.

FIRES FROM ELECTRICAL CAUSES

Fires caused by aircraft electrical systems in British aircraft are now extremely rare.

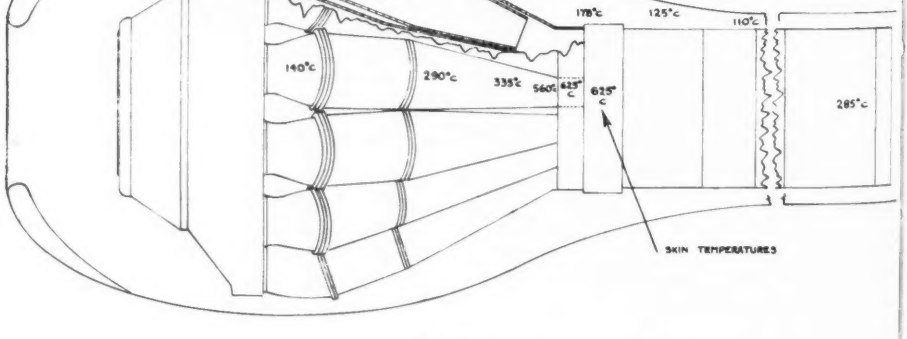

Fig. 9.
Skin and ambient temperatures in typical turbine engine.

This may be attributed to the present stringent requirements for reliability and flameproofness. Such fires as have been investigated have been attributed to one of the following causes:—

(1) Ignition of inflammable vapour by arcs or sparks from non-flameproof apparatus.
(2) Firing of cables and electrical equipment because of short circuits and so on.
(3) Spontaneous ignition of oil, etc., on over-heated electrical apparatus.

Equipment is considered " flameproof " if an internal explosion does not ignite a surrounding explosive mixture. This is achieved by total enclosure or when, as in a large generator, ventilation is necessary, by drawing the ventilating air from an uncontaminated source.

In a few fires the source was a magneto in which the ventilating holes were covered with wire gauze through which petrol dropped from a defective union. The petrol ignited explosively, blowing a hole in the gauze and the flame ignited the leaking petrol which continued to burn and ultimately burnt through the main petrol feed pipe.

Electrical instruments, relays and warning lamp circuits are often made " flameproof " by the limitation of the total current to a value which on break will not ignite petrol vapour.

The risk from the firing of cables, and so on is minimised by the use of protective devices such as fuses and circuit breakers and by the use of cables appropriate to the normal load. Apparatus designed with a short time rating, *e.g.*, electric propeller control circuits, can be protected against prolonged operation by a thermal overload trip.

The main risk of fire from electrical causes external to the aircraft electrical system, consists of the ignition of inflammable vapour by sparks or corona discharge from the accumulation of " static " electricity. There is also, in the event of a lightning stroke, a slight risk of fire from the ignition of other inflammable materials. The accumulation of static charges on aircraft may be caused by hail, snow or rain, by flying in dust clouds, or by the flow of fuel or other insulating fluids in pipes. In flight inflammable vapour may be present in the region of the aircraft during air refuelling or emergency fuel jettisoning and this may be ignited by static discharges at projections on the aircraft, such as the free end of the jettisoning pipe. There is also a risk of fire during ground refuelling because of static generated in the refuelling pipes. This risk increases with increase of speed of delivery, quantity delivered, length of delivery pipe and the insulation resistance of the tank.

The order of the potentials created by the flow of petrol is indicated by the following example taken from tests made at the Royal Aircraft Establishment. In these tests petrol was pumped through a rubber pipe and then through an insulated funnel into an insulated tank. The voltages established on the various components were measured by an electrostatic voltmeter and with a flow of 20 gallons per minute the potential between the tank and earth reached 8,000 volts after a delivery of seven gallons, and between the tank and nozzle 6,800 volts for a delivery of ten gallons. As a guide to the risk involved a discharge from the tank at a potential of 4,000 volts was sufficient to ignite a fuel vapour-air mixture.

MISCELLANEOUS EQUIPMENT

There are many pieces of miscellaneous equipment on an aeroplane which can cause an accidental fire, although evidence suggests that fires originating from these sources are not frequent. The particular equipment that requires attention includes the hydraulic system, the oxygen system, the cabin pressurisation and heating system, thermal deicing systems and auxiliary power units.

The hydraulic system is prone to leakage and fires have been caused by the leakage of the oil-base fluid on to parts of the cabin heating system. Careful positioning of the pipes may reduce the risk by separating potential leaks from sources of ignition, but unless a satisfactory non-inflammable hydraulic fluid can be found we should prefer to see hydraulics replaced by a pneumatic or electrical system.

Some trouble was caused by explosions in oxygen regulators and piping which in one or two cases caused the loss of an aeroplane through damage to a fuel tank and ignition of the petrol. The cause was found to be spontaneous ignition of traces of oil, grease or flux left in the equipment during manufacture. The cure was simple and effective —scrupulous attention to cleanliness during manufacture, repair and maintenance, and warnings against the use of oil or grease on any oxygen equipment.

Fatal explosions have been caused by the misuse of compressed oxygen for inflating tyres or for pressurising hydraulic systems. Oxygen fittings should not be similar to those for compressed air or nitrogen.

Fires in cabin pressurisation systems have been caused by the spontaneous ignition of oil which has leaked into the system.

Combustion heaters for cabin heating or de-icing and auxiliary power units may be potential sources of danger, unless properly installed and maintained and, in general, the basic rules for the prevention of fires in engines will apply to this class of equipment.

On one occasion an aeroplane took off with a flat rear tyre which was ignited by friction. When the wheel was retracted a hydraulic pipe was burnt through, the tail unit was destroyed and the aircraft crashed.

FIRES ON STARTING UP AND SHUTTING DOWN THE ENGINES

It is not proposed to say much about fires which originate on starting the engine or shutting it down, because in the majority of cases they could be avoided by following the appropriate drill.

Non-compliance with the correct starting procedure usually consists of mis-handling of the throttle controls, with the result that an excess of unburnt fuel remains in the induction system of a piston engine, or in the combustion chamber system of a turbine engine.

When starting a piston engine from cold there is a possibility of a " pop " back due to a slow burning mixture. This means that a sheet of flame may travel back through the induction system and any attempt to " catch " the engine on the throttle, will cause a quantity of fuel to be ejected from the accelerator pump and a fire may result. If the engine responds, then no harm is done, as the flames will be sucked out by the air flow through the carburettor. If the engine does not respond, the safest procedure is to motor it on the starter to suck any remaining flames out of the system and if this fails, to extinguish the flames with a fire extinguisher.

It is not possible to give a detailed account of the correct starting procedure for all types of engines, but we would mention that for piston engines it is most desirable that induction system priming should proceed at the same time as the rotation of the engine by the starting motor.

With turbine engines the fuel is injected into the combustion chamber or chambers at the same time as the engine is motored and the only fires experienced during ground running with turbine engines have been caused by a " wet " start. This is on account of the failure to initiate combustion during the engine motoring period and the resultant flooding of the combustion system with liquid fuel. If the fuel is not fully drained off, any subsequent start will ignite the residue, causing long flames to issue from the jet pipe. When the excess fuel has burned completely, these flames will fade away, but it is possible that before this occurs excess fuel from a jet pipe will ignite fuel or inflam-

mable material inside the nacelle or on the ground. Especially dangerous from this point of view is asbestos lagging around the hot end of the engine or jet pipe. This will absorb any fuel leaking on to it during the attempted start or otherwise and when the start is actually made, the heat will vapourise this fuel.

A potential source of danger is the fuel spilt from the various components of the fuel system on a turbine-engined aircraft. These components usually have a common drain projecting through the nacelle and fuel drips directly on to the ground. While the engine is running the spill usually amounts to less than one pint per hour, but on shut-down this is supplemented by the draining of all fuel from the burner manifold. No fires from this free fuel have been reported, but if petrol were used an alternative method of draining would be necessary.

Fires occurring in piston-engined aircraft during the shutting-down period, or sometimes a little while afterwards, have been mainly confined to those in or around the carburettor. With engines liable to backfire, usually because of incorrect tuning, a fire can occur up to half an hour after stopping the engine. Investigation has shown that with this kind of fire a sheet of flame passes through the induction system leaving a small flame burning in the top half of the carburettor. As the throttles are closed, thus reducing the air flow through the carburettor, the small flame continues to burn near the jet and generates heat, whereby the remaining fuel in the float chamber evaporates and increases the size of the flame. Fires of this sort can be prevented by following the correct shutting-down procedure.

PREVENTION OF FIRES

Consideration has been given at some length to the probable causes of fires, and the next step is to outline the basic principles for the prevention of such fires in relation to the detailed design of the aircraft and power units.

Stated briefly, the most obvious precaution to be taken consists primarily of preventing any inflammable material reaching an ignition source and secondly, preventing the occurrence of an external ignition source. At first sight this appears quite impossible because the source of the internal energy for the engine is contained in an inflammable liquid. Until the time approaches when the energy from these inflammable liquids is replaced, by suitable solid fuels or even atomic energy, the aircraft designer must take special care in preventing the ignition of the fuel under all circumstances outside the engine cylinder or combustion chamber.

PREVENTION OF A FIRE IN THE ENGINE

We have seen that the power plant is the most frequent source of danger and therefore should be given special attention by the designer. Assuming the engine is of first-class design mechanically, the first necessity is to be able to stop the engine as soon as the pilot has suspected something to be wrong; this may be indicated by excess vibration, falling oil or boost pressure, rise in coolant, oil, or cylinder head temperature as the case may be. The requirement to be able to stop the engine quickly implies the provision of equipment for the rapid feathering of the propeller in the case of piston and propeller-turbine engines and the shutting off of the main fuel cock in all types.

If successful action is to be taken to prevent a fire in the air from being caused by an engine failure, it is absolutely imperative that the earliest possible warning of impending failure should be given to the pilot or flight engineer so that he may stop the engine before the outbreak of fire.

With modern types of medium and large powered engines, the use of variable pitch propellers is almost universal and this complicates the quick detection of an engine failure, since the constant speed unit will tend to maintain both the engine speed and

boost pressure predetermined by the position of the engine throttles. Warning that something is wrong in a turbine jet engine should, however, be much easier since the rotor speed and jet pipe temperatures are good indications of the engine behaviour.

Several attempts have been made to produce a satisfactory engine failure warning device, but at the present time the only really satisfactory warning system for propeller engines is the torque dynamometer. Mention has been made earlier that the loss of coolant is a source of danger and in an attempt to minimise this, a device was produced and fitted to many aircraft to warn the pilot that his coolant level had dropped below the safe limit.

Of importance is the positioning of the fuel and oil pipes, oil coolers and electrical cables in relation to the exhaust system or combustion chamber system so that there is no possibility of damage because of overheating. It is also important to make adequate provision for the draining of oil and fuel so that no accumulation may remain in the nacelle.

LIMITATION OF THE FIRE

Although improvements in engine reliability and good design of the power plant may make accidental fires in the air less frequent, the risk of primary and secondary fires caused by enemy action still remains. It is necessary to consider all possible means of restricting the spread of a fire so that damage to the airframe and controls is avoided, and extinction is possible. The following requirements are considered essential or highly desirable in this respect:—

(a) Confinement of the fire to the engine nacelle by the provision of a fire-proof bulkhead and cowling, or fire-proof compartment.

(b) Provision for shutting off the fuel and oil supply in such a way that the minimum quantity of liquid is left in the pipe lines. The length and number of pipe lines containing the inflammable liquids in front of the fire-proof bulkhead or inside the flame-proof compartment, should be reduced to the absolute minimum. It is essential for the fuel or oil cocks to be located behind the bulkhead or outside the potential fire compartment.

(c) The use of fire resistant flexible pipes, flexible pipe unions and electrical cables inside the potential fire zone.

(d) Provision of drainage for the nacelle capable of dealing with the maximum possible leakage of fuel, oil and other combustible liquids and the elimination of combustible or absorbent materials in front of the fire-proof bulkhead or within the fire-proof compartment.

(e) Location of the accessory gearbox and accessories behind the bulkhead or in the case of turbine engines away from the hot surfaces of the engine. If this were done the requirements in (b), (c) and (d) would be substantially reduced.

The most important of the above requirements is (a), the isolation of the power units or that part of the power unit containing engine components which are potential sources of fire, by means of a suitable fire-proof bulkhead or walls which will prevent flames from penetrating into the airframe structure. Any components which are likely to have an external temperature greater than 150°C. should be regarded as potential sources of fire.

Figures 10, 11 and 12 show the application of fire-proof bulkheads or compartments to engine installations incorporating an air-cooled radial engine, a liquid-cooled in-line engine and a turbine engine respectively. The fire wall should consist of stainless steel sheet at least 26 SWG and should isolate completely any fire which may occur in the power plant. Any holes in the fire

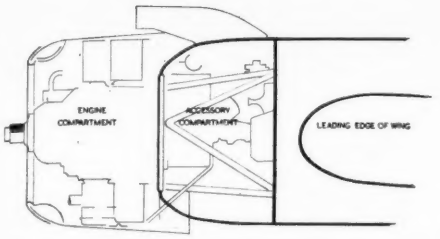

Fig. 10.
Fire-proof compartment air-cooled radial engine.

wall should be sealed by fire resistant bushing. It is also advisable not to place any actuating control gear or electrical wiring, and so on, within four inches of the back of the bulkhead or fire wall. To prevent flames from penetrating the engine cowling at the rear of the bulkhead it is recommended that the cowling in this region should be made of, or covered with, thin stainless steel sheeting for a length of about thirty inches. For the same reason it is advisable to cover that part of the wing leading edges adjacent to the power plant with thin stainless steel sheeting for a width of about eighteen inches on each side of the power plant.

All essential services and structural members for a power unit should be fire-proof or provided with adequate fire protection, or better still, located outside the potential fire zone. The following items are regarded as essential services:—

1. Propeller feathering control and actuating gear.

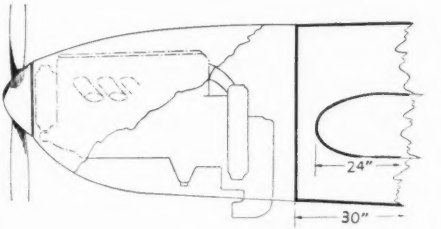

Fig. 11.
Fire-wall for liquid-cooled engine.

2. The fuel cock controls.
3. Fire extinguisher controls.
4. Cooling air control and actuating gear.
5. The aerodynamic control system.
6. The cabin pressurising control.

In piston engine installations it is obviously impossible to locate all the above services outside the potential fire zone and therefore the equipment in front of the bulkhead or within the fire walls must be fire resistant.

Flexible pipes carrying inflammable liquids must be of an approved fire resistant type. Rigid pipes and actuating gear for the essential services should be of steel.

Every possible precaution should be taken against the leakage or spillage of oil and

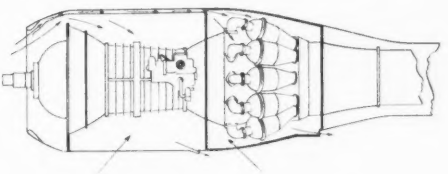

Fig. 12.
Suggested layout of fire compartments and air ventilation for typical turbine engine.

there should be no surfaces on which it can accumulate. A dirty engine must be considered a dangerous engine.

FIRE-PROOFNESS TEST

In stating that pipes, whether rigid or flexible, and structural members should be fire resistant, some standard of fire-proofness is required. During the war a standard paraffin blow lamp was used and the components were required to stand up to the flame for not less than five minutes without failure or dangerous loss of strength. This rough and ready test is now being replaced by a test in which the flame is more precisely specified.

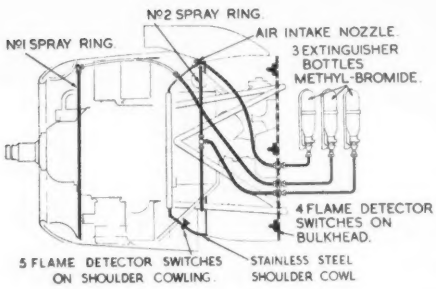
No2 SPRAY RING.
AIR INTAKE NOZZLE.
No1 SPRAY RING.
3 EXTINGUISHER BOTTLES METHYL-BROMIDE.
4 FLAME DETECTOR SWITCHES ON BULKHEAD.
5 FLAME DETECTOR SWITCHES ON SHOULDER COWLING.
STAINLESS STEEL SHOULDER COWL

Fig. 13.
Recommended fire-proofed installation for radial engines (Bristol type).

TANKS CONTAINING INFLAMMABLE LIQUIDS

Tanks containing inflammable liquids in the aircraft should be positioned behind the fire-proof bulkhead with a clearance of at least four inches. The position of the tank should, if possible, be such that in the event of damage caused by enemy action or a crash landing, spilt liquid will not drain on to the bulkhead or into the power plant. If possible the tanks should be crash-proof.

The design of tank filling caps also merits careful attention with the object of preventing any liquid leaking into the tank compartment. In large aircraft pressure refuelling will tend to reduce this danger.

Adequate drains for the airframe and engine nacelles should be provided to ensure that no accumulations of inflammable liquids can occur, either in flight or while standing on the ground. The location of the outlets for the drains and also fuel tank vents should be carefully chosen so that there is no risk of ignition by exhaust gases. In flight the trails from drains or vents and exhaust gases should not overlap.

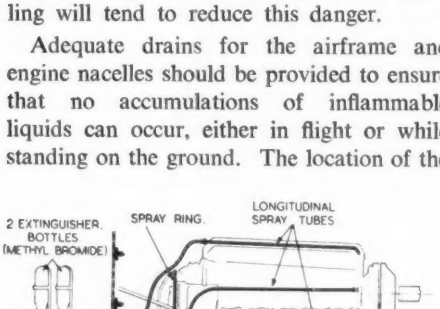

Fig. 14.
Recommended fire-proofed installation for in-line engines.

FIRE DETECTION

Fire detectors have been in use for some little time and before the war usually consisted of one, or at the most two, unit type detectors located on the bulkhead. Obviously such a system is inadequate because it depends far too much on a flame or region of intense heat occurring at the particular spot chosen for the detectors. This defect can be overcome in two ways:—

1. By installing a larger number of unit type detectors in the engine nacelle and accessory compartment at places considered likely to experience flame or intense heat.
2. By installing a "continuous" type detector in the potential fire zones.

During the war a "continuous" type detector was not available and it was suggested that the warning system should be improved, temporarily, by the addition of more unit type detectors. Figs. 13 and 14 show the suggested layouts for an air-cooled radial engine installation and a typical liquid-cooled engine using a number of unit type detectors. Both these were found to work satisfactorily during a series of fire tests simulating fires in flight. On the other hand they could be improved considerably by the addition of more detectors. By far the most satisfactory detection system is the "continuous" type, but much more development work is required to produce a good and reliable detection element, for it will be appreciated that a false warning could be dangerous.

Application of detection devices in turbine engines is similar to that for piston engines and detectors, preferably of the "continuous" type, should be placed in potential fire zones. Fig. 15 shows a suggested

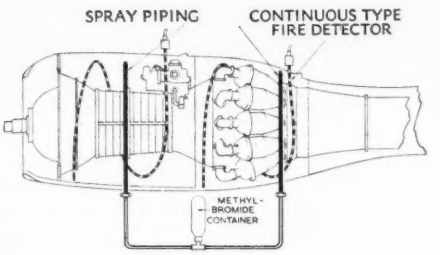

Fig. 15.
Suggested fire detecting and extinguishing system for typical turbine engine.

arrangement for the "continuous" type of detector. Until the results of more experimental work are available on the turbine engine it is not possible to say whether the system is satisfactory or not.

The fire warning device, like many other devices for warning the pilot that something is wrong, is a red light in the cockpit which is illuminated as soon as the detector operates to close an electrical circuit.

EXTINCTION OF ENGINE FIRES IN FLIGHT

Before discussing the sequence of events leading to the successful extinction of an engine fire in the air, a few words about the fire extinguisher apparatus and the principle upon which it works would be useful. Briefly most fire extinguisher systems operate by the ejection of a volatile but inert liquid over the engine or component.

The volatile liquid has a twofold effect:—

1. A smothering action, restricting combustion, and
2. A blanketing action, whereby the access of air is prevented from reaching the flames.

The cooling effect caused by the rapid evaporation of the liquid is not great on account of the small quantity of extinguishing agent used.

The two liquids which are most commonly used for this purpose are methyl bromide (CH_3Br) and carbon dioxide (CO_2). Table 1 shows the physical properties of both liquids. Carbon tetrachloride has also been tried but was not considered as effective as methyl bromide or carbon dioxide.

TABLE 1

	Methyl bromide CH_3Br	Carbon dioxide CO_2
Molecular weight ...	94.94	44.00
Specific gravity ...	1.732	0.77
Boiling point °C ...	4.6	– 78.5
Melting point °C ...	– 93	–
Cu. ft./lb. of gas or vapour at 20°C and 760 mm.	4.05	8.75
Sp. gravity of gas or vapour at 0°C and 760 mm. (relative to air)	3.27	1.52

Full-scale engine tests were made at the Royal Aircraft Establishment before the war on a number of proprietary fire extinguishing devices, some of which used methyl bromide and some carbon dioxide, but weight for weight, methyl bromide was found to be the more effective and, because of its lower vapour pressure as compared with carbon dioxide, it can be carried in lighter containers. As a result of these tests it was decided to adopt methyl bromide and this has been used ever since in this country. In the United States carbon dioxide found favour, chiefly on account of its availability compared with methyl bromide, but recent tests made by the U.S. Civil Aeronautics Administration agree with the Royal Aircraft Establishment results in placing methyl bromide before carbon dioxide.

APPLICATION OF THE FIRE EXTINGUISHING LIQUID

Very little factual data are available to indicate the amount of methyl bromide required for fire extinguishing purposes in relation to the size of the engine. It is generally agreed, however, that the rate of

discharge of the liquid is more important than the quantity, since the latter is very small anyhow. Such fire installations as were fitted to aircraft before the last war were equipped with one bottle containing 6 lb. of methyl bromide liquid in a nitrogen atmosphere under a pressure of 60 lb./sq. in. at normal temperatures. This amount of methyl bromide was considered sufficient to extinguish a carburettor fire at the time when the carburettor was generally supposed to be the main source of fire.

The fire extinguisher system of this period developed by the Graviner Co. used one bottle to inject some liquid into the carburettor and at the same time to eject the remainder as a blanket of inert gas around the engine. This blanket was produced by means of a distribution system consisting of $\frac{3}{8}$in. o/d piping perforated by 200 holes of 1/32in. diameter. The electrics of this system were connected directly to the fire detector so that the latter automatically operated the extinguisher. The early investigations by the Accidents Investigation Branch showed that this system, used with the original fire drill, was unsatisfactory and instructions were issued to disconnect the fire detector from the extinguisher circuit to enable the pilot to operate the new drill, already described, and bring his engine to rest or at least to low RPM before applying the extinguisher. This modification together with the addition of a warning light in series with the fire detector, improved the effectiveness of the original system. It was also apparent that the amount of methyl bromide from one bottle was insufficient to deal with a really large fire.

FULL-SCALE ENGINE FIRE TESTS

As the investigations proceeded a number of problems appeared relating to fire extinguisher systems, their operation and capabilities, and it was with a view to solving some of these problems that full-scale engine fire tests were started at the Royal Aircraft Establishment in 1942. Naturally the answers to these queries were required as quickly as possible and hence the apparatus set up to study the problem was largely an improvision. The two basic

Fig. 16.
Equipment for Pegasus tests.

Fig. 17.
Equipment for Merlin tests.

types of engine chosen were (1) an air-cooled radial engine (Pegasus XVIII) and (2) a liquid-cooled in-line engine (Merlin II). A third engine, a Wright Cyclone air-cooled radial engine was also included for reasons given earlier. Rather than take up time installing these engines on specially prepared test beds, it was decided to conduct the tests with the engines in one of their respective airframes. (*Note*: These particular engines were chosen to represent basic types as regards general arrangement and not because they were more liable to fire than other types. This also applies to the airframes, for it was just chance that rendered these particular aircraft available for this work.)

Figure 16 shows the Pegasus engine ready for test together with the operating platform and oil pre-heater. The latter piece of apparatus supplied oil at temperatures up to 120°C and at a flow rate of 30 gallons per hour to 120 gallons per hour, depending on the nature of the test. The platform contained the fire extinguishing switches and warning lights and also provided a good viewpoint for the observers and photographer. The engine was operated in the normal way from the pilot's cockpit, and fuel and oil were supplied from the respective fuel and oil tanks in the aircraft.

Figure 17 shows the Merlin installation. The only major difference in arrangement was the provision of external engine controls as it was not possible for obvious reasons to operate the engine from the cockpit.

To cope with an emergency, each installation was fitted with three sets of fire extinguisher bottles so that in the event of the fires getting out of control, two more attempts could be made to save the equipment. If this failed, the airfield fire tender

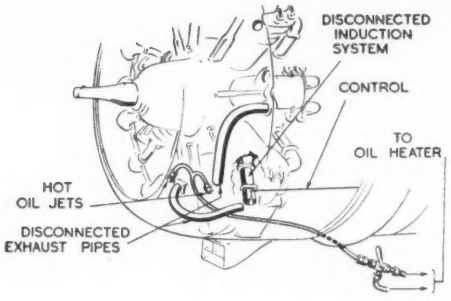

Fig. 18.

Apparatus added to engine to simulate mechanical failure and subsequent fire due to oil and boosted mixture.

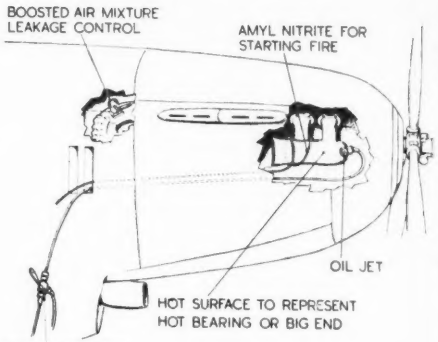
BOOSTED AIR MIXTURE LEAKAGE CONTROL
AMYL NITRITE FOR STARTING FIRE
OIL JET
HOT SURFACE TO REPRESENT HOT BEARING OR BIG END
HOT OIL CONTROL

Fig. 19.

Experimental equipment on Merlin engine.

and crew were always at the "ready" to give assistance. It is interesting to mention that with more than 100 fires, the ground fire crew were only called in on two occasions, while the proportion of fires correctly extinguished was about 80 per cent.

As far as possible the tests were made to simulate fires caused by mechanical failures resulting in the ignition of lubricating oil and/or boosted fuel air mixtures and fuel. To obtain the effect of flying conditions another aeroplane was placed in front of the test aircraft and produced an equivalent air speed of 60 m.p.h.

Figures 18, 19 and 20 show diagrammatically the methods adopted for imitating the various types of failure on the three installations. The experimental arrangement of the fire extinguisher spray piping on the three engines was similar to that shown in Figs. 13, 14 and 21 for the recommended installations, except the Pegasus installation, which had an additional spray ring located near the exhaust collector ring.

For each type of failure, the duration of fire was increased progressively from 5 to 30 seconds before taking any action to extinguish it. There was also a delay between the start of the fire drill and the application of the methyl bromide to the spray pipe system to correspond to the time taken to feather the propeller.

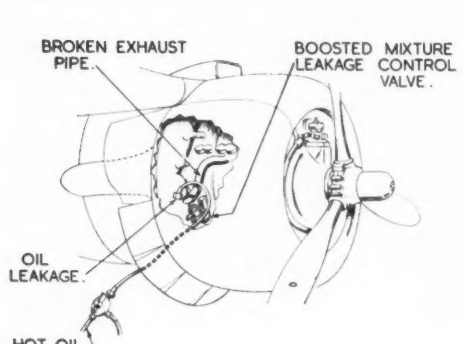

Fig. 20.

Experimental equipment on Cyclone engine.

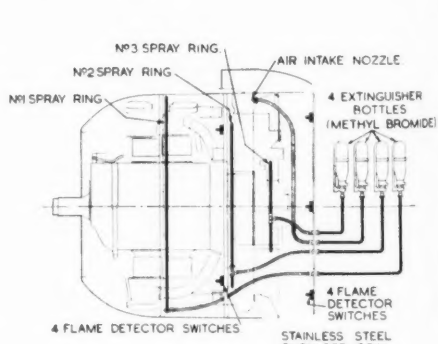

Fig. 21.

Recommended fire-proof installation on Cyclone engine.

Figure 22 shows a typical oil fire on the Pegasus engine just before action was taken to stop the engine. Figs. 23 and 24 show boosted mixture fires on the Merlin and Cyclone engines, the latter at night.

RECOMMENDATIONS AS A RESULT OF THE FULL-SCALE TESTS AND ACCIDENT ANALYSIS

Through the combined efforts of the C.I. Accidents, the Ministry of Aircraft Production and the Royal Aircraft Establishment, several suggestions were made for the improvement of the fire extinguishing equipment and its operation. These are outlined briefly below:—

Fig. 22.
Typical fire in air-cooled engine.

(1) The recommended general layout of the fire extinguisher spray piping for the three basic types of piston-engined power plants are as shown in Figs. 13, 14 and 21, while Fig. 15 shows the suggested layout for a typical turbine engine. The material for the spray piping should be steel, suitably protected against corrosion. In each installation it will be observed that one bottle of methyl bromide is provided for the carburettor intake for the triple purpose of assisting the stoppage of the engine, for dealing with any carburettor fire, and the prevention of burning in the exhaust system.

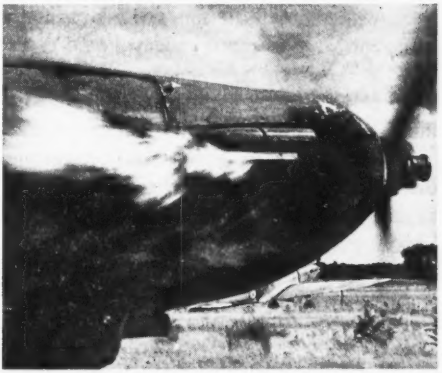

Fig. 23.
Typical fire in liquid-cooled engine.

(2) The average rate of discharge should not be less than 2 lb./sec.

(3) The amount of methyl bromide to be used in the fire extinguisher spray rings varies with the particular layout of the power plant and is probably some function of the airflow through the nacelle and of the engine power. For air-cooled installations of 2000 h.p. the weight of methyl bromide recommended varies from 12 to 18 lb., *i.e.*, two or three bottles. For liquid-cooled installa-

Fig. 24.
Typical fire in air-cooled engine—Rear exhaust collector.

tions with a small air flow, 6 lb. was found sufficient. For more recent liquid-cooled installations, such as the Rolls-Royce Universal power plant, a corresponding increase in methyl bromide is recommended to allow for the increased air flow through the nacelle and also for the increase in engine power.

(4) The unit type of flame detector was not entirely satisfactory and recommendations were made for the development of a "continuous" type.

(5) The fire proofing of flexible pipes by asbestos sleeving although effective, was only recommended until suitable fire resistant pipes were developed.

Fire extinguisher equipment of the type indicated in (1) and used in conjunction with the modified pilot's fire drill was found very effective in extinguishing a large proportion of the test fires.

An important point in the fire drill is the "delay" period between the operation of the feathering switch and the operation of the fire extinguisher spray rings. This "delay" period is approximately 10 to 12 secs. duration, at the end of which time the propeller is fully feathered. It is, however, necessary to inject methyl bromide into the air intake as soon as the fire drill begins in order to stop combustion in the engine or exhaust. Bearing in mind the advisability of reducing to a minimum the mental and physical effort required by the pilot, especially during a time of stress, a scheme was devised in which, provided that the fire detector has operated, the action of pressing the feathering switch brings into action a system of relays which turns off the fuel and oil, starts the injection of methyl bromide into the air intake and after the prescribed delay, switches off the ignition and discharges the remainder of the methyl bromide around the engine.

Various components for this scheme have been designed and are being tested. It will be appreciated that a scheme of this sort must be absolutely fool-proof before its adoption can be recommended.

WEIGHT OF THE ENGINE FIRE EXTINGUISHER EQUIPMENT

The question of weight is of great importance for both military and civil aircraft and many designers will wish to know how much additional weight to allow for in the provision of the recommended fire extinguisher equipment. Table 2 summarises the approximate weights for the equipment suitable for a liquid-cooled in-line engine and air-cooled radial engine, both of approximately 2000 h.p.

TABLE 2

Item	ENGINE	
	Liquid-cooled 2 bottle system	Air-cooled 3 bottle system
Fire extinguishing apparatus	lb.	lb.
(a) Spray pipes and connections ...	9.0	6.0
(b) Methyl bromide, bottles & brackets	24.0	37.0
(c) Electrical equipment	9.0	9.0
Fire proofing of pipes and controls ...	3.0	3.0
Total ...	45.0	56.0

The weight of the equipment as fitted to aircraft before the war was approximately 20 lb., so that the modified equipment amounts to an increase of 25 and 36 lb. per engine for the liquid-cooled in-line and air-cooled radial engine respectively. The above weights do not include the fire-proof bulkhead and cowlings because it is considered that such precautions, designed to limit or restrict the spread of fire from the engine to the airframe should be regarded as a standard feature of any installation.

FIRE EXTINGUISHERS FOR AUXILIARY POWER UNITS AND COMBUSTION HEATERS

The fire extinguishing equipment for auxiliary power units is similar to that for

the main power units except that methyl bromide is discharged simultaneously into the intake and around the engine and that operation is initiated automatically by the fire detectors which also cut off the fuel supply and the ignition. Similar equipment should be provided for combustion heaters, using carbon dioxide if there is any possibility of leakage into a passenger compartment.

CRASH FIRES

If an aircraft diving out of control strikes the ground at such a speed that the occupants are killed by the impact and the tanks are burst and the fuel scattered, fire almost invariably starts immediately. Fortunately such an accident occurs extremely rarely in civil flying or to the larger types of military aircraft. But fire too often follows a heavy forced landing in which the aircraft suffers little structural damage and most, if not all, of the occupants escape fatal injuries. We propose to discuss the causes of fire in this type of accident and the methods by which fire can be prevented or its spread minimised. We do not propose to deal with the extinction of fire by ground equipment but will confine our suggestions to preventive design features and to airborne extinguishing equipment.

The United States Air Corps full-scale crash tests in 1924, in which obsolete aircraft were run head-on against a concrete wall at a speed of about 100 m.p.h., showed that when petrol was scattered over an engine fitted with an exhaust manifold and long exhaust pipe, fire usually occurred and appeared to originate inside the broken exhaust, but if short exhaust stubs were fitted fire rarely broke out.

Laboratory and full-scale tests at the Royal Aircraft Establishment confirmed the danger of ignition in the interior of a hot exhaust pipe. Table 3 gives the approximate minimum igniting temperature of fuel and oil inside a 6 inch diameter pipe compared with that on an open hot plate, and with the flash point.

TABLE 3

	Minimum spontaneous igniting temperature °C		Flash point °C
	In 6 in. steel tube	On open steel plate	
Petrol (unleaded)	245	Over 670	−42
Aviation fuel 100 octane (leaded)	390	Over 670	−42
Kerosene	214	650	+42
Hydraulic fluid	235	400	150
Lubricating oil	300	430	250

Although the above figures are approximate and may vary somewhat with the conditions of experiment and the nature of the sample, they are significant (1) in the wide gap between closed and open igniting temperatures, (2) in the effect of the addition of lead tetra-ethyl to the closed igniting temperature, (3) in the smaller gap with the less volatile fluids and (4) in that a low flash point is accompanied by a high open igniting temperature.

The open igniting temperature represents the conditions least favourable to ignition and if there is any enclosure of the hot surface such as a flame-damping shroud round an exhaust pipe the igniting temperature will tend to fall towards that in the closed tube. The closed test appears therefore to be the better criterion in assessing the risk of spontaneous ignition. It is well known that various additives like lead tetra-ethyl raise the spontaneous ignition temperature, and research is still being done on this problem.

If a fire breaks out in an engine the hazard to life is not great unless it spreads to the main fuel supply. Whether fuel escaping from a broken pipe outside the power plant is ignited depends on the flash point, since as long as the fuel temperature remains below the flash point an inflammable vapour-air mixture cannot be formed and the fuel will not ignite. There is no doubt that the overall hazard is reduced by the use of fuels of flash point above the normal ground temperature.

Investigation of crash fires during the war showed that the majority of fires originated in the power plant and started in the ignition by the hot exhaust system of oil escaping from the constant speed unit or feathering gear, broken as the propeller struck the ground, or ignition of fuel by the exhaust system, or by an electrical short or a spark from a broken cable. A few fires were thought to have resulted from ignition of escaping fuel by heat generated by friction or by a spark from the impact of metal on stone. In one case an explosion took place while rescuers were moving a broken wing: presumably the source of ignition was a spark from damaged electrical wiring.

It was found that the incidence of fire was low when the speed of impact was below 80 m.p.h., but rose rapidly with increasing speed.

To achieve maximum protection against crash fires two simple principles should be followed: (1) that all combustible fluids should be kept as far as possible from potential sources of ignition, and (2) that all fuel, oil and hydraulic systems and also exhaust systems should be so constructed and located that they are least likely to be damaged on crash.

The exhaust or jet pipe outlets should be high so as to avoid damage and the entry of inflammable vapour or liquid spray. If they are below the wing they may strike the ground and come to rest in a pool of fuel or oil or in contact with dry grass providing almost ideal conditions for spontaneous ignition. All tanks, pipes, coolers, and so on, carrying inflammable liquids should be so located that in the event of damage fluid will not leak on to any hot surface where it may ignite spontaneously or produce an explosive vapour-air mixture. All potential fire zones in the power plant should be separated from each other and, of course, from the airframe. The amount of fuel and oil in a fire zone should be kept to a minimum. Combustion heaters for cabin heating and de-icing should be located so that they are unlikely to be damaged and should not be near tanks or pipes carrying inflammable liquids.

To prevent spread of fire it is essential that fuel should not escape from the tanks. Fuel pipes emerging from the bottom of, and running below, wing tanks are liable to be wiped off and consideration should be given to top outlets with means of preventing siphonage should a pipe be broken between tank and engine. A combination of this system with a flexible bag tank may be the best solution.

The function of the Graviner extinguishing system in a crash or heavy landing is mainly preventive. It is discharged by an inertia operated switch located low down in the fuselage on a stiff member at the position of probable maximum deceleration. As now fitted to reciprocating engines, part of the methyl bromide is injected into the induction system and simultaneously the remainder is sprayed around the engine, carburettor and exhaust system with the object of assisting the engine to stop, rendering inert any unburnt fuel which may pass through the engine, and of providing an inert blanket around the engine until the exhaust system has cooled to a safe temperature. New developments include devices for cutting off the flow of fuel and oil to the engines and for isolating the accumulator from the electrical system, except those circuits which are required for the extinguishers, dinghy release and the like.

To assist the ground fire fighting squad to deal with a fire inside the power plant a spring-loaded panel is fitted in the nacelle cowling so that the nozzle of an extinguisher can be inserted and the extinguishing medium be discharged at the seat of the fire. One or more extinguisher switches should be accessible from outside the aircraft for use by the ground staff, if deceleration has not been sufficient to trip the inertia switch, or if the pilot has not been able to operate the extinguisher.

In the past fires in the air in civil aircraft have not been frequent and the authors believe that the risk will become less as the principles of fire prevention are followed in aircraft design and with the adoption of turbine engines. Therefore, the risk of crash fires will become relatively more important and we suggest that in designing a fire fighting system for any civil aircraft the main aim should be prevention of crash fires.

ENEMY ACTION

Most of the bomber aircraft lost through enemy action in the last war were brought down by fire. This is understandable because the fuel tanks and the engines present a much greater target than the pilot, the main structural members, and the vital controls. Moreover, the pilot and the controls could be given considerable protection by armouring. Few aircraft survived an explosion or fire in a single tank. Engines were not so vulnerable as a strike could only cause a fire directly if fuel or oil pipes were fractured, although an engine that was damaged and continued to run was likely to go on fire through fuel or oil leakage or when complete failure occurred.

Bullet proofing of tanks gave considerable protection against small calibre ammunition as sufficient petrol was rarely drawn through the exit hole to ignite and burn on the outside of the tank and subsequent leakage was not enough to form an explosive mixture inside the wing, which might have been ignited by a second strike.

However, there was a risk that an explosion might be caused in the space above the fuel by an incendiary or by the impact of an inert bullet or shell fragment on a metal baffle. Early in the war an investigation was made at the R.A.E. into the conditions in which an explosive mixture can occur in a fuel tank. In Fig. 25a the area marked "equilibrium conditions" represents the temperature altitude relations within which the vapour-air mixture in equilibrium with the liquid is explosive. "Breathing" either in climbing or diving weakens the mixture and restoration of equilibrium by evaporation and diffusion is slow. In consequence the danger zone is extended to higher temperatures. For example, the vapour-air mixture in the upper part of the space may be explosive at ground level when the tank temperature is about 15°C. It was established by correlation of tank temperatures, rates of cooling and ambient air temperatures that tanks in bomber aircraft could often contain explosive mixtures, particularly in long flights at high altitude and with low air temperatures.

The obvious remedy was an inert atmosphere above the fuel and a system was developed in which compressed nitrogen was fed to the tanks to replace the fuel used and to maintain equality between the internal tank pressure and atmospheric during a dive. The flow of nitrogen was controlled by a valve fitted to the tank vent which maintained the internal pressure slightly above atmospheric. A safety valve was fitted to admit air if the supply of nitrogen failed to maintain the tank pressure equal to atmospheric. This system was adopted by Bomber Command towards the end of the war.

Figure 25b illustrates the danger in tanks containing kerosene. The temperature range in which an explosive vapour-air mixture can occur is higher than with petrol. Although the mixture will not be explosive below 42°C at ground level, a tank temperature of 30°C becomes dangerous at about 30,000 ft. When one considers that at a speed of 600 m.p.h. the aircraft temperature may be some 36°C above that of the ambient air, it will be seen that the tank temperature will often be within the danger zone. If the tank temperature is below the danger range for vapour-air explosion there is still a possibility of ignition. If an incendiary strikes the tank from below and emerges from the fuel inside the tank it will

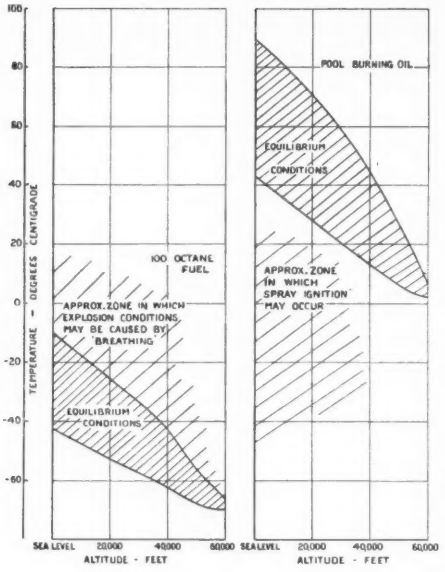

Fig. 25 a and b.
Zones of inflammability.

carry with it a spray of fuel which may ignite explosively. The range within which spray ignition may occur has not been established but that it is extensive was shown by an explosion which was produced at $-23^{\circ}C$ which is $65^{\circ}C$ below the flash point of the fuel. There is no doubt that inert gas protection is as necessary with kerosene as with petrol.

Bullet proofing gave little protection against 20 mm. incendiary or explosive incendiary ammunition, both of which were effective in starting fires outside the tanks. To counter this risk a tank fire extinguisher was developed. This consisted of one or more extinguisher bottles containing methyl bromide connected to a spray ring surrounding one or more tanks. Each tank bay with its extinguisher formed a separate unit and as far as practicable was sealed off from the rest of the wing. The bay was ventilated and drained by a suction louvre so that fuel leaking from a damaged tank was removed as rapidly as possible so as to minimise the possibility of ignition by an engine or by a second strike. A continuous-type fire detector which consisted essentially of a pyrotechnic fuse in a plastic covering operated a switch which discharged the bottles.

This type of equipment gave successful results in semi-full scale wind tunnel tests and is now being fitted to a number of aircraft.

Damage to the hydraulic system caused a number of fires which could often be extinguished by hand extinguishers, although if the oxygen system was damaged simultaneously so that the oxygen was fed to the flames, extinction was almost impossible. This occurred rarely in British aircraft as the hydraulic and oxygen systems were usually well separated. A few fires were started when the flash from a punctured oxygen cylinder impinged on doped or undoped fabric.

CONCLUSIONS

Although we may confidently expect that fires, in civil aircraft at least, will become a negligible hazard, this cannot be brought about unless fire prevention is considered as a major design requirement. Heavy weight penalties need not be involved in adherence to the simple principles of fire prevention such as:—The separation of combustibles from sources of ignition; the use of tanks and fuel systems resistant to the effects of heavy landings; the avoidance of unnecessary inflammable material; and the elimination of leaks in fuel and oil systems.

ACKNOWLEDGMENTS

The authors wish to acknowledge their indebtedness to the Ministry of Supply, and the Director of the Royal Aircraft Establishment for permission to present this paper. They also wish to acknowledge their thanks to the Chief Inspector of Accidents, Air

Ministry, who was mainly responsible for initiating the investigation in 1942 and to Mr. N. G. Bennett and others of the staff of the Accidents Investigation Branch who played an active part in the collection of data on fire accidents and in suggesting remedial measures. Grateful thanks are also due to many colleagues in the Royal Aircraft Establishment, who were associated with the practical work, among whom may be mentioned Mr. Farmer who also assisted in the preparation of this paper, Dr. Parker, Messrs. Gould, Follett, Hudson, MacLennan and Grove-White. They are also indebted to Mr. Williams and his colleagues in Air Ministry Fire Services for their co-operation in the study of crash fires.

FILMS

Films were also shown by Mr. Glendinning. The first illustrated an engine fire, showing the catastrophic results of failure to fit extinguishing apparatus. By contrast, it demonstrated that the methyl bromide extinguisher was very effective in dealing with such fires, both in air-cooled and liquid-cooled engines. Some night photographs showed clearly the rapidity of extinction. The film also illustrated the protection given to a fuel tank against internal explosion by the provision of an inert atmosphere above the fuel and also, the effectiveness of an automatic fire extinguishing system in dealing with a fire in the wing space around the tanks.

DISCUSSION

Mr. Marcus Langley (*Fellow*): Fire prevention would remain for some time one of the most important subjects that aircraft engineers could tackle.

There had been some who thought that with the gas turbine and its kerosene fuel, they were now entering upon a fire-free era. The figures in Table 3 of the paper, showing the minimum spontaneous ignition temperatures and flash points of fuels, would raise grave doubts whether they were really so near that happy day. Although kerosene would appear to render less likely the starting of fires which spread so rapidly in the event of a crash, in other conditions it could have dangers which were greater than those applying to petrol.

During the discussions on turbines in 1946, Air-Commodore Worstall had raised the same point made by the author about reducing the leakage of fuel and oils, and had said that quite 90 per cent. of the servicing troubles with turbine aircraft in his Command were associated with the fuel system, and many of these were caused by small leaks. The problem of providing leak-proof joints offered a profitable field for designers; the tackling of those apparently minor details would lead to the solutions of the major problem.

The inertia type crash switch was widely used in this country and in the United States, but it seemed that the use of the inertia principle for operating the crash fire apparatus was wrong; he believed that it could be shown statistically that a considerable number of crash fires had occurred in such conditions that no type of inertia switch could have been expected to work.

The view expressed by the authors about the use of fuel tanks which might be used to afford greater safety was widely held, and in spite of the evidence that existed against all-metal integral type tanks, they were still used. He had heard it said that if they used the integral type tank they could get many more gallons of petrol into an aircraft and that those extra gallons would make commercial flying profitable. What a price to pay for profit! He believed that every type of aircraft built in any quantities had provided at least one, if not more, crash fires at some time in its career, not necessarily caused by the design of the aircraft, but because of the various circumstances which did cause crash fires. Therefore, they could deduce that one

or more specimens of those aircraft which now had integral tanks would crash fire. The wing, distorted as it would be by the crash, would provide a direct path for the fuel to escape from the inside of the wing on to the heated structure around it.

Air-Commodore Vernon Brown, C.B.E., O.B.E. (Chief Inspector of Accidents, Ministry of Civil Aviation, *Fellow*): At the beginning of 1941 it had looked as if the accident rate would overtake the production rate. In 1942 the statistics had shown that, in the class of engine failure accidents, approximately 8 per cent. of all the fatalities were the result of fire in the air. He had asked for special authority, and financial approval from the Treasury, for the recruitment of extra staff to tackle the problem. The results of the investigations were given to the Ministry of Supply and the R.A.E. When the R.A.E. had collected sufficient data a remarkable demonstration had been staged to which were invited representatives of the manufacturers and designers.

Shortly after the demonstration a paper was produced by Mr. Glendinning, of the R.A.E. and Mr. N. G. Bennett, of the Accidents Investigation Branch and it had marked the beginning of publicity on the subject. The paper was very valuable indeed and was known as C.H.404. It had been given wide publicity because it had been produced as an R.A.E. document.

The loss of Mr. Bennett to the Accidents Investigation Branch was an undoubted gain to the Graviner Company.

One of the most important measures which could be taken to prevent the spread of fires was to instal warning devices. He was convinced of the necessity for ensuring that a pilot should have ample warning of the occurrence of a fire in his aircraft. The crew of a bomber, for obvious reasons, could not wear parachutes all the time they were on duty; and when urgent action was necessary they had not time to get their parachutes from the stowage bay and they were up against the difficulty of an exit. In civil aircraft the exit problem again loomed large, and the psychological effect of parachute drill on fare-paying passengers had to be considered. But if there could be boat drill aboard ship, surely there could be parachute drill, which was the same kind of instruction, in civil aircraft. It was a matter which was receiving continuous careful consideration, and was one which must not be shelved.

Fire meant urgency; there was no time to think what could be done after a fire had started, and it was essential that a pilot should have immediate warning of the outbreak of fire in his aircraft. Far too many cases had arisen during the war in which pilots had not known that their aircraft were on fire; in so short a time as a minute a wing could become so badly embrittled or burned as to bring about failure in the air.

In 1943, the B.O.A.C. flying-boat the Golden Horn, had caught fire and soon afterwards had crashed into the River Tagus. A period of 2½ minutes was the maximum which could have elapsed between the outbreak of the fire and the diving of the boat into the water. Yet, when the wreckage was recovered, it was found that the elevators were completely burned. If that could happen within 2½ minutes, then that fact emphasised the urgency of dealing with a fire in the air.

It was surprising still to find that some pilots did not know their fire drill; that had been brought to his notice two or three times even in the past twelve months. The new fire drill had paid handsome dividends; it should be broadcast to everybody concerned, with details of what each action represented and why. It was given careful thought at the time it was brought into use by the R.A.F., and it should be broadcast to all the world.

Mr. N. G. Bennett (Graviner Manufacturing Co. Ltd., *Associate*): The author had referred to the publication of the findings of

the Fire Prevention Sub-Committee of the Aeronautical Research Council in 1922, and to the publication of accidents data in 1942. When they read the 1922 paper (of which they had had no prior knowledge), those who had been working in the Accidents Investigation Branch had been considerably humbled, to realise that the findings at which they had arrived in 1942 were precisely the same, basically, as those of 1922. Obviously design for fire "*prevention*" in aircraft had not been given the attention it deserved during that intervening period of twenty years. The emphasis had been on fire extinction.

He had been even more dismayed recently when speaking to several American aircraft manufacturers and airline operators, to find that the average airline man or manufacturer in America had a much better grip on the fire prevention problem than had his counterpart in this country. Did Mr. Glendinning, who seemed to have been in the fire prevention business longer than anyone else, feel that it was time they had in this country a virile and widespread organisation, on the lines of the non-profit organisation in America which was linked with the National Fire Protection Association? Such a body should be responsible for spreading information to the manufacturers. Information such as that obtained by Mr. Glendinning and his colleagues 20 years ago was much better known in the United States than in this country. Much was happening in America and not enough in this country. The designers themselves were much more acutely aware of how the power plant and aeroplanes could be protected against the outbreak of fires, whereas in this country there was a dangerous tendency to overload aircraft with extinguishing equipment as insurance against risks which could, and should, be designed out of the aircraft.

Dr. E. W. Still (Rolls-Royce Ltd., *Fellow*): There had been an undue emphasis of fires in the power plant in the paper, and the risk of fires in the aircraft had been treated rather as an afterthought.

Considering that wings were full of petrol, the leading edge of the main planes lined with fuel pipes, hydraulic pipes and electric cables, without thinking of the similar maze of equipment under the floor of the cabin, serious consideration should be given to these items, particularly in cases of belly landings.

His Company had barred the use of hydraulic systems forward of the power plant bulkhead because of the fire risk.

In designing power plants for world-wide use it had been found that the necessary fire detectors were not available in England, as the C.A.A. demanded satisfactory operation a second time to detect a re-strike of the first fire. They also called for a system capable of extinguishing a second fire and the British Aircraft manufacturers should bear this in mind.

The author had suggested that fire extinguishing should be automatic; he in turn suggested seriously that before this could be achieved, someone should pay a little attention to propeller feathering times, as his experience on different types of aircraft was that this could easily exceed 30 seconds.

Another point of importance was that his Company had great difficulty initially in meeting the C.A.A. requirements for hoses for fuel and oil pipes, as satisfactory types were not available in England.

With the help of the R.A.E., Rolls-Royce had set up various rigs in order to set fire to the pipes and units and to make official fire tests. These had culminated finally in full-scale power plant fire tests resulting in satisfactory clearance of the fire prevention, detection and extinguishing items, but at the same time had shown the need for a revision of the British fire clearance tests, for hose connections in particular.

This had also been reflected in America where the Constellation fires had resulted in such a severe tightening up of the C.A.A. requirements as to make it doubtful whether

any of the latest British pipes would meet the new proposed American specification.

In fact, it was suggested that the proposed American specification should be scrutinised carefully and seriously by the A.R.B. and British manufacturers generally before it was allowed to become part of the P.I.C.A.O. requirements.

Mr. Ralph Poole (Poole and Partners, *Associate Fellow*): The work described in the paper had been done by a small team of people in the R.A.E.; and if the small amount of money that had been spent on the work was known and if it could be related to the amount of money involved in the Industry, the result would be surprising.

To emphasise how dangerous fuels could be, he showed a diagram, illustrating that approximately one-eighth of a cubic inch of inflammable liquid such as petrol, lubricating oil, or hydraulic fluid would make one cubic foot of explosive mixture; that was almost 14,000 times the original volume of liquid.

A portable instrument had been developed for the Services during the war for measuring the inflammability of atmospheres. With it they were able to study the inflammability or combustibility of gases and they had obtained information regarding fuels which was rather new, or at least which gave a better picture.

The characteristics of some oils, altitude being indicated by the vertical axis and a temperature scale by the horizontal axis, were plotted on Fig. 1. One of the oils, kerosene, was not so safe as many people imagined. The heavy line on the graph indicated the lower inflammable limit and the dotted line the upper inflammable limit. Kerosene was explosive at 44°C. at ground level, and would give an explosive mixture at 45,000 ft. altitude and 20°C.

Similar tests on lubricating oils had been made by him in co-operation with the R.A.E., the Shell organisation and Mr. Hardy, Assistant to the Director of Research and Development for Civil Aircraft. One of those oils was explosive at 110°C.—120°C. at ground level, and it would be explosive at about 90°C. at 40,000 ft.

Another oil, having exactly the same lubricating properties when used on a bearing, for instance, was safe at about 220°C. at

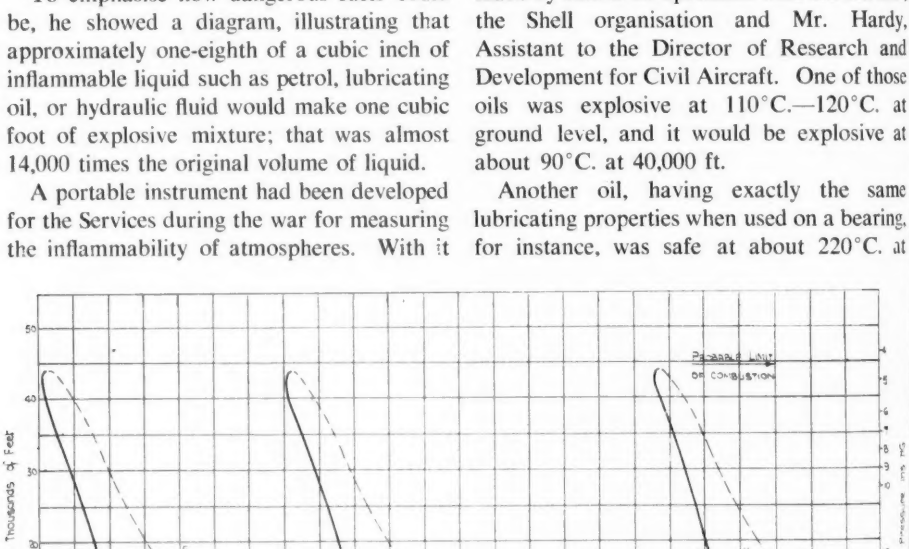

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Fig. 1.

Variation of inflammability of engine oils with altitude and temperature.
Two oils having similar viscosities but of different composition are compared with kerosene
N.B.—Curves for oils estimated from results of low temperature tests.

ground level, and also at about 195°C. at 40,000 ft. Those two oils met the same Air Ministry specification in regard to lubricating properties.

Thus, supplies could be obtained from different bulks of apparently similar oils from day to day and the results from the inflammability point of view would be totally different. Lubricating oils could easily be made less inflammable and that was one of the problems now receiving attention.

On a further graph evaporation curves were plotted for various lubricating oils, or the relative combustibilities. The tests were made at low temperatures on a number of oils, several of which had the same lubricating properties. The relative combustibilities varied in the ratio of 10:1 in the initial stages, in some cases. The relative combustibility of one fell rapidly with time and then remained constant, whereas the relative combustibility curve for another oil fell less rapidly. Some of the mixtures were extremely dangerous; and the ordinary method of measuring flashpoint erred on the side of danger rather than safety.

With a tubular element, having a concentric conductor in a space filled with a chemical compound, resistance characteristics had been obtained, and the results of the work seemed promising. Another graph compared the resistance characteristics of four compounds with those of the metals platinum and copper on a logarithmic scale. The change in the resistance of the compounds with temperature was considerable. Between 0° and 100° the resistance was reduced from 1,000 to 10 ohms per centimetre length. They were sensitive over the range of temperature from 300° to 450° or 500°.

Thus it was possible, by suitable control of chemical compounds, to make a relatively simple continuous detector element which would operate over any chosen temperature range.

In the interests of safety in the Aircraft Industry and in industry generally, every designer should be reminded that only a small drop of petrol was needed to produce a great deal of explosive gas. The same applied to lubricating oil; it was only a matter of bringing about the necessary rise of temperature or fall of pressure. It was not sufficiently well known that a flash point related only to the pressure at which it was measured; in many cases the reduction in pressure corresponding to an increased altitude resulted in an alarming reduction in flashpoint temperature.

Mr. W. G. A. Perring (Royal Aircraft Establishment, *Fellow*): Following the work done twenty-five years ago, a final report had set down the fundamentals on which fire prevention should be based; the recent experiments had brought that work up to date and had decided the layout of the extinguishing system in modern power units.

Whereas the emphasis in the early work was to deal with fire prevention methods, the emphasis towards the end of the period with which the paper had dealt was on the serious fire and explosion risk consequent upon enemy action. It had been fairly well established that something like 75 to 80 per cent. of the bombers which had been lost during the war were lost ultimately by reason of fire. In consequence, the methods of blanketing the fuel in the tanks were developed. If integral tanks continued to be used for fuel storage in aircraft, did the authors think that the application of blanketing schemes would be justified for the purpose of crash fire prevention?

He agreed with the importance of research into the less inflammable lubricating oils and similar research was needed into the less inflammable hydraulic liquids and systems. The Americans had gone a long way to develop a hydraulic fluid which was non-inflammable.

Were the authors satisfied that the present arrangements for fire prevention covered the new risks introduced by the necessity for

pressure cabins, air-conditioning, and de-icing? That important aspect concerned the aircraft designer chiefly. Was the aircraft designer taking proper measures to deal with the new risks which would certainly develop as civil aviation developed?

Mr. S. H. Clarke (D.S.I.R.): It would be wise to search for a non-inflammable type of lubricating oil, rather than just an oil having a higher ignition temperature; lubricating oils would undergo a certain amount of change in the course of time and the resulting compounds would ignite at a temperature much lower than the original ignition point of the oils. Originally they might have a lubricating oil with a high ignition point, but the ignition point might become quite different later. Therefore, a non-inflammable type was really required.

Mr. Bennett had referred to the National Fire Prevention Association of America; towards the end of 1946 the Fire Offices' Committee of this country had announced the formation of a Fire Protection Association here. At the present moment its activities were limited by its size, but it was hoped that before long it would accomplish something quite as useful as had been accomplished by its American counterpart. Mr. W. H Tuckey, formerly the Chief Technical Officer of the Fire Offices' Committee, had joined that organisation, and he would try to deal with any suggestion made. The main point was to disseminate information; he pleaded for the fullest application of the knowledge they already had.

Captain J. Dolezal (*Associate*) *contributed*: Showing the fire-fighting films to air crews would probably be the best way to increase their confidence in the fire-fighting apparatus carried in aircraft and also would bring to their attention the necessity for a correct fire-drill.

In most of the big aircraft the main petrol cocks were under the supervision of the flight engineer. The lecturer had stressed the fact that an intensive fire might burn through a main spar in one minute. Immediate action by the pilot was of paramount importance. An emergency (or master) remotely-operating fuel control installed within the pilot's easy reach would enable him to act instantly and co-ordinate appropriately the rest of his fire and cockpit drill. The remotely-operated cocks might be located near the engine. This was not yet a design requirement for civil aircraft, although an instant and properly co-ordinated action by the pilot in civil aircraft was just as vital in case of fire as in any other aircraft operating in more hazardous circumstances.

Were integral tanks considered leak-proof if an aeroplane accidentally became over-stressed by flying through an especially rough turbulence?

D. Cameron Douglas (*Assoc. Fellow*) *contributed*: A slide had shown two of the continuous type switches, installed in a jet unit, in the suggested layout of a system for dealing with fire in the air.

Had such switches actually been tried in jet engines and if so, in the air or in ground simulated fires?

He could see certain difficulties in their use as the temperatures might vary considerably at various points. He thought that point switches operating at different temperatures in different zones might be necessary.

Many jet engines were running at present without anything to provide a warning for the pilot, save the jet pipe temperature.

This was not sufficient as in a recent jet engine failure, followed by fire, the pilot stated that there was no irregular rise in the jet pipe temperature.

It was necessary from the manufacturer's point of view to know exactly what was required in order that suitable apparatus might be built, and, from the pilot's point of view, to have it incorporated quickly.

Had experiments been made to ascertain the degree of temperature variation and the actual temperature, both minimum and maxi-

mum, that would be experienced at different points?

A question had been asked about inertia switches not operating under certain conditions. The answer was fairly plain. If a pilot made, say, a belly landing which was smooth enough *not* to operate the inertia switches (set at 69) then he was not likely to be unable to take precautionary fire prevention measures and press the switch. He understood that frangatory switches could easily be fitted to either wing tip and under the belly if necessary to take care of light forced landings.

Mr. G. Palmer (R.A.E.) *contributed*: The findings of the "youngsters" in the recent work were closely similar to those of the earlier workers of twenty-five years ago, and he deplored the fact that greater prominence had not been given to those findings.

As one of the "old uns" closely associated with Dr. J. E. Ramsbottom in that work at the R.A.E. he would add that the problem was shelved (much to their disappointment) during the after-the-war period, in which the amount of flying was naturally greatly reduced, and when the fire risk was judged to be of small importance. It was the death, in a crash fire, of the French Air Minister which again called attention to the fire risk.

Mr. J. G. M. Pardoe (Air Registration Board) *contributed*: Dr. Still's remark that the Air Registration Board's requirements called for fire extinguishers to provide two adequate discharges and Mr. Glendinning's reply that that was a point of difference between himself and the Board, deserved some further comment.

The Board did not require "two-shot" systems until P.I.C.A.O. called for them in its Airworthiness Standards and the Board was bound to reproduce this requirement for International Transport Category A aeroplanes.

At the P.I.C.A.O. Airworthiness Division meeting in March 1947 the matter was reopened by the Board's representatives. It transpired that one of the main reasons of the original proposers of the "two-shot" requirement was to provide a better chance of extinguishing one fire. They considered it desirable to guard against the possible failure to function of a one-shot system and, as is possible in some systems, the possibility of all the extinguishant being inadvertently expended in the wrong power plant. Neither of these being satisfactory reasons for calling for more than one system provided that it really was adequate, the Board's representatives urged the amendment of the "two-shot" requirement and obtained the addition of a let-out clause to the effect that "individual 'one-shot' systems shall be allowed in main power plant installations where equivalent safety can be demonstrated fully."

It would now be possible for the Air Registration Board to accept single-shot systems where it was satisfied that the design of the power plant and extinguisher system was such as to guarantee that they would be fully effective.

In due course, after technical discussion with the parties involved in this country, it could be expected that the British Civil Airworthiness Requirements would be suitably amended.

MR. GLENDINNING'S REPLY

Although they were getting a great deal more co-operation from designers than when they had started the work six or seven years ago, they would like to have the opportunity of considering new projects at an early stage rather than be called on to suggest modifications in a design which was fundamentally dangerous. He agreed with Dr. Still that, if the belly of an aeroplane were filled with cabin heaters, electric wiring, fuel and hydraulic pipes and lined with absorbent material, fire could hardly fail to follow a crash landing.

They were looking into the question as to whether blanketing schemes would be useful

in systems with integral tanks, to prevent the spread of fire in the event of a crash, but he preferred not to say much about it at the moment because their ideas had not been developed far as yet.

The Americans had a hydraulic fluid which was non-inflammable; but how successful it was for hydraulics he did not know yet.

(*Mr. Perring*: He had 60 gallons of water-based hydraulic fluid and would be able to give information about it shortly.)

Mr. Glendinning: He preferred the pneumatic system from the fire risk point of view.

The Director of the new Fire Prevention Research Association was Mr. S. H. Clarke. That body had been established only recently and it was necessary to give it a little time to get things going and to establish co-operation among the various people working on the subject. There were many people working on it at the Ministry of Civil Aviation, the Air Ministry, the Ministry of Supply, the Department of Scientific and Industrial Research and in the Aircraft Industry. He hoped that the aviation section of the new body to which Mr. Clarke had referred, would get the same whole-hearted support from its members as did its very lively counterpart in the United States.

The development of non-inflammable lubricating oils was an ideal at which to aim, because they knew that the heavier oils, particularly when subject to cracking, were liable to spontaneous combustion. He appreciated Mr. Poole's work, which was aimed at reducing the inflammability of oils by increasing the flash point, but considered that more attention should be given to raising the spontaneous ignition temperature. An immediate reduction in fire risk could be achieved, as Mr. Langley had pointed out, by the development of leak-proof hydraulic and oil systems. Was it too much to ask that an engine which had run 300, 400 or 500 hours should look as clean as those which had recently been exhibited at Farnborough?

He agreed entirely with Air-Commodore Vernon Brown that the development of a warning device was most urgent; Dr. Still had said that he could not find a detector which complied with the American requirements. His first requirement would be for a detector which would detect quickly; if it could incorporate automatic re-setting, so that it would give warning of a second fire, well and good. That quality, however, should not interfere with rapidity of detection.

He and his colleagues had not yet had an opportunity to examine the American schedules. Mr. Bennett's remarks had suggested that the results of the work done in 1922 had not reached the British manufacturers. The results of the work were published in 1922 in the Aeronautical Research Council's reports and memoranda and should have been available to the manufacturers. It was interesting that the findings in 1942 were not very different from those in 1922, although conditions were somewhat different.

The risk of explosion in the tanks, and so on, was not so great in civil aircraft as in military types. There might be ignition because of lightning, but few crashes had occurred which had been attributable to that cause. The electrics were extremely good nowadays.

The provision of an installation which would extinguish a second fire, if it occurred, as well as the first, was perhaps asking rather too much; it would involve a heavy weight penalty. It might be possible to devise a scheme which would deflect some extinguishing fluid and make it available to one engine from a second engine, should the fire in the first engine break out again. But he would prefer to put all his eggs into one basket and to have a 95 per cent. chance of extinguishing the first fire, rather than a 75 per cent. chance of putting out each of two fires in turn.

(*Dr. Still*: It was a requirement of the A.R.B.)

Mr. Glendinning: He appreciated that that was so, but it was a matter on which they differed.

As new designs of aircraft came along, new problems arose, and he and his colleagues were doing their best to meet these problems.

The films which had been shown were merely records of experimental work. An instructional film had been made and others were being prepared for the purpose Captain Dolezal had suggested. Mr. Bennett and he had stressed, in their report in 1943, the importance of grouping controls necessary for the fire drill and had suggested a scheme which automatically completed the drill after the pilot had operated a single switch. He hoped it would not be long before such a scheme was made a design requirement for all aircraft. The hazard from slow leakage from integral tanks, which might develop in flight, could be minimised by adequate ventilation. The main risk was that the tanks would burst on crashing.

Work was continuing on turbine engine nacelle temperatures. There was a tendency for the temperatures to increase above those shown in Fig. 9. A continuous type detector was approved for temperatures up to 85°C. and was therefore available for most reciprocating engines and for tank bay systems. Work was being done on a number of continuous and unit types capable of withstanding higher ambient temperatures. The arrangement of the detector in Fig. 15 was a tentative suggestion.

He was grateful to Mr. Pardoe for his explanation of the attitude of the Air Registration Board towards the single-shot system. He thought that if that system were fully effective it would be a pity to deprive another engine of its extinguishant which might be needed if the aircraft made a heavy landing—a possible contingency with one engine out of action.

Mr. R. B. Farmer: The criticism of the British manufacturers in regard to the development of fire protection was, to a large extent, premature. If the Americans were ahead of them in respect of fire protection, the lead had been gained very rapidly and, since 1944, because at that time a Fortress power plant with a complete fire extinguishing system designed at Farnborough was flown to America for test there.

The manufacturers in this country might be a little less responsive than their American counterparts just at present; but he did not think the lead which the Americans could have gained during the past year at the most could be very great. In the DC-4M aircraft the original positions selected for the extinguishing bottles, namely 50 ft. from the power plant, gave the impression that fire protection was an afterthought in the aircraft design. Also, no provision had been made to use the extinguishing fluid in the event of a crash, although statistics in America had shown that two crash fires occurred for every one in flight, with potentialities of there being four to every one in flight.

Dr. Still had referred to trouble in feathering propellers on a well-known civil aircraft; action had already been taken to overcome this difficulty and a mandatory A.R.B. requirement stipulated a maximum feathering time of ten seconds in all conditions. He was not quite sure how the American insallations compared with theirs in that respect, but in 1944 they had learned from flight experience at Farnborough that there was no guarantee that a Fortress propeller could be feathered above 10,000 ft. Regarding the new American fire test conditions for flexible pipes, there was every reason to believe that a new type of pipe which met the British requirements would also satisfy the American requirements.

He agreed that the development of continuous detectors should be aimed at and he hoped that an R.A.E. detector, tested under Dr. Still's supervision during the previous week, offered some hope of ultimate success.

It was continuous, it was re-setting, and it had detected the fire in less than two seconds; the fire had remained alight for nearly a minute, and the detector had indicated the extinction of the fire. A subsequent successful functional test of the detector indicated that it would have worked again in a second fire. Its development represented a rather hasty R.A.E. effort, but fundamentally it gave a ray of hope.

No American or British continuous re-setting detector had yet had R.A.E. approval. It was most important that no detector should cause an unnecessary return to base through inadvertent operation, as had been reported on a trans-Atlantic flight.

REVIEW

Aircraft Strength of Materials. H. D. Conway, M.A.(Cantab.), Ph.D. Chapman & Hall Ltd., London, 1947. 256 pp. 21s.

This book provides a clear and straightforward treatment of beams, struts and frame works, which should be of considerable value to draughtsmen wishing to acquire a sound theoretical knowledge of these subjects. For the stressmen, use of the book is likely to be somewhat restricted as knowledge of the subjects treated now constitutes only a small part of what is required for the stressing of present-day aircraft and the book only devotes one brief chapter to the all-important subject of stressed skin construction.

The book is carefully written and well produced.

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CAUTIONARY NOTE REGARDING SOME CHEMICALS USED FOR TRANSITION INDICATION

by

R. C. PANKHURST, Ph.D., A.F.R.Ae.S.

SUMMARY.

THIS note draws attention to the poisonous properties of certain chemicals which have previously been used for transition indication in wind tunnels, indicates which alternatives are safe, and suggests general precautions.

INTRODUCTION.

In the 1946 Wilbur Wright lecture,[1] reference was made to the china-clay method[2] of indicating the transition of a boundary layer to turbulence. Since then it has been realised that such chemicals as nitrobenzene, if used indiscriminately, are liable to produce ill-effects on personnel.[3], [4] The purpose of the present communication is to indicate these risks and to suggest precautions which are considered advisable. The "chemical" method of transition indication[5] is likewise reviewed.

THE CHINA-CLAY METHOD.[2]

This has become a standard method for observing boundary layer transition in wind tunnel experiments. The china-clay is applied to the wing surface in the form of a paint, using a spray gun. The application is allowed to dry and is then rubbed down to a smooth finish. For the transition observations, the prepared surface has been sprayed[2] with nitrobenzene, nitrotoluene, chloronaphthalene, safrole, eugenol, ethyl benzoate, methyl salicylate, ethyl salicylate, or glycol.[6] Of these, methyl salicylate and ethyl salicylate are now recommended as unlikely to produce ill-effects on personnel; the use of nitrobenzene, nitrotoluene, chloronaphthalenes and glycols should definitely be discontinued. The properties of the various substances are indicated in the following table; they are discussed in detail from the medical point of view in reference 4.

Spray	Properties	Recommendation
Nitrobenzene	Poisonous	Should not be used
Nitrotoluene	,,	,, ,, ,, ,,
Chloronaphthalenes	,,	,, ,, ,, ,,
Safrole	Used in cheap soaps	Unlikely to produce ill-effects
Eugenol	Occurs in oil of cloves	No known risks
Ethyl benzoate	Not poisonous	Use acceptable
Methyl salicylate	Considerable safety margin	Recommended for general use in this work
Ethyl salicylate	Even safer than methyl salicylate	
Glycols	Poisonous; effects tend to be cumulative	Should not be used

THE CHEMICAL METHOD.[5]

In this method the wing surface is first spray-painted with a chemical; a reactive gas is then allowed to exude as a thin filament from a narrow spanwise slit in the surface. The extent of the area over which the reaction takes place is shown by the resultant colour change, thus indicating the position of transition of the boundary layer.

The reaction commonly used is that of hydrogen sulphide on lead compounds. This gas, however, is extremely toxic even in small concentrations; lead sprays, too, are both dangerous and cumulative in their effects. It is recommended strongly that the use of these chemicals should be discontinued.

It is rather difficult to choose an alternative, because nearly all the common gases which are chemically active are, by that very fact, highly toxic as well. The most promising possibility seems to be ammonia, which has already been used with success,[5] and is not likely to be harmful in the concentrations involved.

GENERAL PRECAUTIONS.

During spraying operations, the immediate risk to personnel can be reduced by working from outside the tunnel or by the use of an airline respirator, but the contaminated air would later be continually recirculated round a return-circuit tunnel or through the room housing a straight-through tunnel. The repeated use of sprays may build up considerable concentrations of vapour in a return circuit; besides the poisonous effects of toxic chemicals, there may also be a risk of explosion. In the straight-through type of tunnel the concentrations of vapour are less, but the personnel are exposed continually.

It is recommended that the working section should be screened off and ventilated during spraying. In a small tunnel this could readily be done by means of retractable wooden partitions; for a large tunnel, recessed roller blinds are suggested. Ventilation should be provided by means of a fan with trunking from the working section to outside the building. In a straight-through tunnel it is also advisable to provide suitable general ventilation of the tunnel room in order to remove fumes introduced in the "chemical" method or arising from the evaporation of the liquids which are repeatedly applied in the china-clay method.

ACKNOWLEDGMENT.

The medical information was provided by Dr. E. R. A. Merewether, H.M. Senior Medical Inspector of Factories.

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CORRESPONDENCE

DESIGN FOR MAINTENANCE

In general I agree with Lt. Bowden's comments on Design for Maintenance.

I have been associated with the aircraft profession for a number of years, the majority of which have been from the maintenance point of view. I have also been closely allied with the design field and one of the major faults, as I see it, is the lack of facilities for co-operation between the design office and the field operator.

One thing I have noted in some engineering departments is the appointment of checkers of drawings. In the majority of cases a checker is selected from the draughting personnel purely for his drafting and design experience. My personal opinion is that a checker of production drawings should be thoroughly familiar with manufacturing procedures and with final assembly.

I can recall a case of a wing attachment fitting to a fuselage in which, because of the close proximity of a gusset, a special jack had to be designed to extract the attachment bolts.

Another point is the inaccessibility of the rear of most instrument panels. I could quote several cases in which to remove an instrument it has been necessary for the maintenance man to enter the cockpit head first, twine himself around the control column, support himself on his shoulders on the cockpit floor, and reach up to the rear of the panel.

A comment I have heard for many years past has been "the two basic requirements for an aircraft mechanic are (1) he should have the patience of Job and (2) he must be an excellent contortionist."

Could not the entire instrument panel be hinged to swing inwards to give access to a person sitting in the cockpit?

Another complaint I have encountered is the close proximity of the rear of an engine with its fire-proof bulkhead.

Accessory drive components on the rear of most radial aero engines are compact to say the least, even on the engine stand. The supporting studs of a starter or generator are awkward to get at considering the small clearance between such items as the fuel pump, hydraulic pump, vacuum pump and so on, particularly as in some cases the nuts are locked with locking wire. How much more difficult it becomes to change one of these units once the engine is installed in the airframe when, as often happens, a matter of three to six inches space exists between the component and the fire wall.

I agree with the suggestion of Mr. B. Jackson in his letter, of better recognition of the Technical Publications Department and also his suggestion of improved liaison between the design office and the flight shed. This has been my opinion for a long time.

Since the general trend in aircraft requirements seems to be, "How can this aircraft operate more safely, more economically, and with the least number of general servicing hours?" the aim of the designer should include "if this piece goes wrong, how soon can I change it?"

In conclusion, may I add that the actual financial value of an aeroplane is to keep it in the air; therefore, this must be accomplished by not so much a minimum of maintenance but a minimum of *time* for maintenance. This definitely can be improved.

An enginer with an A and C licence in a design oflce would be a great asset.

T. G. Cribb, M.I.Ae.S., Associate, Canada.

From the correspondence published in the May issue of the JOURNAL it is obvious that a general feeling exists that the maintenance design standard of aircraft is not high enough and should be improved.

My short paper was not intended to cover all the maintenance faults; if that had been my intention it would have been easy to fill several journals.

The correspondence backs up and adds to my points. I should like to have seen the comments of more personnel on the design side. Perhaps seeing the word "maintenance" they did not bother to read the paper and passed on to more abstruse subjects.

I think that I can add to my remarks by giving suggestions for a better set-up in the design oranisation which would improve matters.

In the first place I should not let a drawing be issued to the shops without it being vetted by a practical maintenance man who would pass it in a similar manner to the Stress section. This would mean giving someone considerable authority as they must be allowed to hold up a drawing if necessary and call for an alteration, or in drastic cases, re-design.

As a suggestion, the personnel required might be one senior maintenance expert plus two junior men per aircraft. Also, and I think this is very important, this team should have permanently attached to it a member of the Royal Navy, Royal Air Force or Airline (according to which type of aircraft is being designed). This last representative must be up to date in practical matters and not someone who has not actually worked on aircraft for a long period of time. In the past aircraft firms have often got their own way (*i.e.* by not incorporating improvements at an early stage in production and so on) because of the lack of up-to-date experience of the Service member.

The above team working on the aircraft and following the design through the mock-up stages in the experimental shop and into the production lines should do much to help the maintenance engineer. A member of the team should accompany the aircraft on all its trials and he must get down to the job of maintenance himself. Wearing a pair of overalls and handling spanners is the only real way of finding out at first hand the snags and difficulties.

The ideal aircraft from the maintenance engineer's point of view is the one requiring the least amount of maintenance. That is to say, everything should be designed to last out until the aircraft is due for a major inspection. It should not be necessary to open up and examine or remove components and assemblies after completing a comparatively small number of flying hours.

I am a great believer in leaving well alone. The more a component is handled the more are the chances of something being damaged or re-assembled incorrectly. The only servicing for normal flying should be the removal of cowlings to check obvious defects, right through to the major inspection. It should not be necessary to remove cowlings at all for day-to-day flying. What would a car owner think of the designers if he had to spend an hour every morning unscrewing panels, looking at many components, before he could drive off?

The above remarks have been written to try and further drive home to the aircraft manufacturers the need for better "maintenance design."

T. E. G. Bowden, Lt.(A) A/E Royal Navy, Grad.R.Ae.S.

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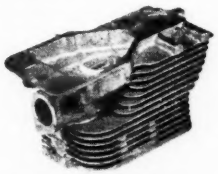

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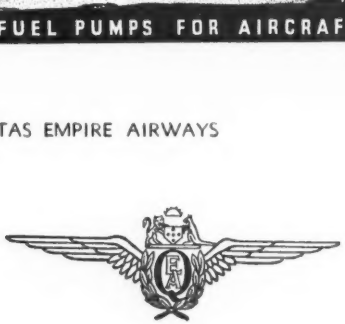

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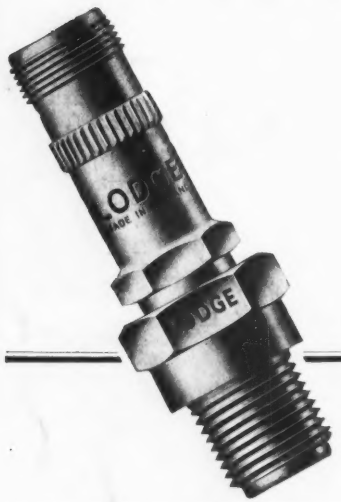

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